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AFIT/GSO/MA/88D-2



LIGHT SATELLITES - A DILEMMA
FOR THE U.S. ARMY

THESIS

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# LIGHT SATELLITES - A DILEMMA FOR THE U.S. ARMY

THESIS

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James R. Pierson

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## Abstract

The purpose of this study was to assist senior Army leadership in determining whether light satellites (LIGHTSAT) should be procured to meet current and future reconnaissance, surveillance and target acquisition (RSTA) needs on the battlefield. Two methodologies were developed during this study - the decision analysis approach and the analytical hierarchy process. For each methodology, LIGHTSAT was evaluated against the Joint Surveillance Target Attack Radar System (JSTARS) alternative. Due to this being an unclassified study and that the effort was centered on developing methodologies, sample data was used in place of actual values (unless otherwise noted). The decision analysis methodology required an influence diagram of the overall decision, a value model that elicited outcomes for each alternative, a model that would help determine the level of reconnaissance, surveillance and target acquisition achieved by each alternative and an assessment of probabilities of certain events occurring. Detailed discussion was given to the development of the value model and to how reconnaissance, surveillance and target acquisition are measured. The use of decision analysis lends considerable insight into the decision through the

expected value of perfect information (EVPI). EVPI illustrates how much additional money should be invested into reducing the uncertainty within the decision.

The analytical hierarchy process analyzed the decision through a hierarchy of objectives approach. Subjective judgments based upon experience were combined with quantifiable measurements to apply weightings to the various criteria within a level of the hierarchy. Preferences between the alternatives were then made. The synthesis of these preferences between alternatives and weightings yielded an overall preference for the decision. Sensitivity analysis of the hierarchial structure offered insight into the criteria that might alter the decision.

Among the recommendations provided was the need to validate these methodologies with actual classified data. Continued emphasis on enhancing the capabilities of the military commander through the use of space assets was considered essential.

# LIGHT SATELLITES - A DILEMMA FOR THE U.S. ARMY

## I. Introduction

> I can guarantee only two weeks against an all-out Warsaw Pact attack - then we will have to use nuclear weapons. (26:114)

This is the assessment of the military balance in the European theater today by the Supreme Allied Commander Europe, General John R. Galvin. This assessment is double that of his predecessor. The United States has adopted a concept, named Competitive Strategies, that aims at "aligning Western technology strengths against enduring weaknesses in Soviet war-fighting doctrine" (26:114). The goal of this strategy is not to match system against system with the Soviets but to focus in on a few key programs that studies and analysis have indicated will provide critical leverage on the future battlefields. One of these programs considered vital is centered around the gathering of real-time intelligence (26:114) that would be used by battlefield commanders in execution of current doctrine.

The U.S. Army's basic operational concept is called Air-Land Battle doctrine. This doctrine (fully defined in FM 100-5) is primarily based upon "securing or retaining the initiative and exercising it aggressively to defeat the

enemy" (7:2-1). A commander on the next battlefield must know as much as is possible about the enemy and the area within his concern in order to be effective.

> To be effective, the commander must ... avoid the enemy's strengths and exploit his weaknesses, ... know when and where to concentrate combat power. To do so, he must know the area of operations, the conditions, and the nature, capabilities, and activities of the enemy. (7:6-1)

Execution of Air-Land Battle doctrine requires the capability to "see" deep behind enemy lines in order for the operational commander to secure the initiative. The requirement to "see" is highly dependent upon an all weather, all terrain, day-night reconnaissance and surveillance system that is responsive to the tactical commander's needs. Lacking this capability, Clausewitz' concept of the friction of war appears. "Friction ... is the force that makes the apparently easy so difficult" (4:121). The lack of an accurate and timely intelligence network introduces doubt and uncertainty onto the battlefield. The effects of uncertainty contribute towards hesitation and indecision within the echelons of leadership.

There is concern within the Army leadership that a shortfall exists in current capabilities to provide the necessary and timely intelligence information required by tactical commanders to fully execute Air-Land Battle doctrine on future battlefields. The intelligence data

needed by commanders is composed of reconnaissance, surveillance and target acquisition information (RSTA).

A joint Army and Air Force program, Joint Surveillance Target Attack Radar System (JSTARS), is currently under development with a goal of filling the void in the tactical intelligence arena. This project is scheduled to be fielded in the early 1990's at a cost of over $4 billion.

The Army's Training and Doctrine Command (TRADOC) is also actively examining ways in which Air-Land Battle requirements for the future can be met through space systems. For example, it is hoped that by the turn of the decade, the Global Positioning System (GPS) and MILSTAR will contribute towards military capability improvements in positioning and communications, respectively (17:4).

Another concept that is gaining attention is the use of small, lightweight, inexpensive, single purpose satellites to help fulfill RSTA and communication missions. This concept, dubbed many names, is now called LIGHTSAT. The Defense Advanced Research Projects Agency (DARPA) is currently responsible for the development of the LIGHTSAT concept under its charter of high risk and high technology development. If the concept is proved to be a viable one, then it will be up to one of the services to assume full program responsibility for continued development and deployment.

The Army leadership is rapidly advancing towards a decision that is centered around whether investment in small satellite technology is a worthwhile and acceptable risk in view of the Army's needs and requirements. In an environment of competing priorities and shrinking budgets, any new and emerging combat system must possess the potential of upgrading the combat capability of the deployed forces in a most cost effective manner.

## Problem Statement

The Army operational commander (theatre or corps) requires timely and accurate intelligence information in developing and executing battlefield plans to decisively engage and defeat the enemy. The two alternatives studied in this effort will be a LIGHTSAT system and the Joint Surveillance Target Attack Radar System (JSTARS). The two alternatives will be discussed in Chapter 2. The present status of intelligence will be the baseline against which the other two systems will be compared.

Space systems hold the potential to assist the tactical commanders in gaining RSTA information in a timely manner. However, a space system that can be controlled by battlefield commanders to assist in RSTA missions is not cheap. In today's political, economic and military environment, the decision to acquire a space system comprised of light satellites is an extremely complicated

one. In all likelihood, acquisition of a major space system would mean trading off current or proposed combat systems. The question that looms over the horizon for the Army leadership is - should the Army invest a considerable sum of money over the next decade in a light satellite space system to meet the RSTA needs of the battlefield commander?

## Research Objective

The objective of this study is to develop a methodology to analyze whether the Army leadership should pursue use of light satellites in fulfilling some of their battlefield requirements, specifically in the RSTA arena.

## Scope of the Study

This effort is an analysis of a strategic decision that the Army is facing in the near future. This study will focus in on the costs, benefits, risks and alternatives associated with the decision that impact upon the decision makers.

As LIGHTSAT is an emerging technology program and much of the information pertaining to RSTA capabilities is classified, a concrete solution is not sought after, but rather a methodology is developed by which the Army leadership might approach this problem.

There will not be any effort placed into designing specific, technical characteristics of a satellite system. The effort of this study will be directed towards providing

a methodology to assist Army decision-makers in determining whether LIGHTSAT, with a RSTA focus, should be acquired.

Methodology

There will be two methodologies taken in this study. The first methodology will center around the decision analysis cycle. Decision analysis is a normative, not a descriptive, approach to making decisions. It is a process for determining how a decision should be made based upon logical and rational thinking (13:25). The decision analysis technique is able to incorporate the elements of uncertainty and risk into the decision making process.

In order to fully accomplish the decision analysis, measures of effectiveness (MOEs) and a value function relating all the components of the decisions will have to be derived. Chapter 3 will fully develop the methodology described above.

The second methodology will be the analytical hierarchy process (AHP). This process structures the subjective judgments of the decision maker in determining the preference of the decision maker. The MOE's will be the same as those used in Chapter 3. Chapter 4 will develop this methodology in depth.

Neither chapter will attempt to find an actual answer as the data that is used in both Chapters 3 and 4 is sample data and does not reflect actual measurements.

## II. Literature Review

The concept of lightweight and inexpensive satellites has been circulating throughout the Department of Defense for several decades. The initial generation of satellites developed and launched by the U.S. in the 1960's were true LIGHTSATs. However, as the nation's requirements grew in line with technological developments, LIGHTSATs evolved into large, multi-roled and expensive satellites. Over the past two years, the concept of LIGHTSATs fulfilling a cost-effective role in the attainment of Army doctrinal war fighting objectives has garnered considerable attention.

Air-Land Battle is the current war-fighting doctrine for the Army and Air Force. For operational commanders, success on the next battlefield depends upon the four tenets of Air-Land Battle: initiative, depth, agility and synchronization (7:2-1). These tenets are highly dependent upon the ability to determine the enemy's intent. Timely and accurate intelligence information derived from a variety of RSTA sources provide the battlefield commander a significant capability in estimating the enemy's courses of action.

### LIGHTSAT

In seeking to make Air-Land Battle doctrine more effective, the Army has placed emphasis on employing

advanced technologies in finding solutions. Col. David Jackson, head of the Army Space Technology and Research Organization (ASTRO), stated "There's no question space is a new frontier for ground combat. The Army must be prepared to move into it" (1:3). Lt. Col. Ronald Forkenbrock, chief of the concepts and studies division at the Army Space Institute (ASI), emphasized the linkage between our doctrine and space support when he said, "Seeing deep is critical and space gives us the necessary redundancy needed for deep operations" (1:3). Furthermore, in the fall of 1987, a panel of industry experts on space recommended that the Army fully support DARPA's efforts in the development of LIGHTSAT because space systems could play an important role in Air-Land Battle warfare (28:3-4). Potential missions that a LIGHTSAT system may perform include the following:

1. Gathering of operational intelligence that can augment data currently gathered by national level systems.
2. Communication, navigation and weather support for tactical forces.
3. Reconstitution of satellite systems.
4. Decrease wartime dependence on fixed launch facilities.
5. Provide inexpensive space support for low intensity conflicts.
6. Provide a surge capability for crisis situations. (30:1-2 and 6:2)

(This thesis concentrates on the first mission listed above).

The agency responsible for the development of the LIGHTSAT program is DARPA. Based upon the Packard Commission report, DARPA was assigned a greater role in supporting the operational commands. One way in which this will be achieved is through a prototyping mission. By working with specific commands and their unique needs, it is hoped that high risk, high yield technologies can be developed more quickly (30:2).

As discussed earlier, LIGHTSAT - a most recent DARPA project (funded at $35 million in FY 1988 and $34 million in FY 1989) - is aimed at developing a family of lightweight satellites. A former director of DARPA's advanced strategic technology office, Dr. John Mansfield, believed that a new generation of satellites were needed.

> Current satellites are very expensive and last for many years, and I agree that they are the most efficient way to spend space budget dollars. However, there is a growing need to develop new types of satellites that can supplement or replace existing satellites in times of conflict. (25:64)

A former LIGHTSAT program manager, Mr. William T. Marquitz, believes that LIGHTSATs will begin a new era for military commanders in space. In discussions with operational commanders, Marquitz says that the message is loud and clear, "give me an organic asset I can control in times of conflict" (23:22). Marquitz also argues that LIGHTSAT and the Strategic Defense Initiative (SDI) complement each other

very well (23:22).

DARPA's position on the LIGHTSAT program has always been to demonstrate available technology to see if LIGHTSAT can be of any use to the operational commanders in complementing current national satellite systems (23:22). If the LIGHTSAT concept was deemed feasible and of benefit, one of the military services would assume control of the program.

The current director of DARPA's Advance Satellite Technology Program, Mr. George Donohue, sees modern technology as the driving force behind increasing satellite capability while reducing satellite size and cost. Examples of this type of technology are lightweight binary optics, gallium arsenide and very high speed integrated circuits (19:2). He has assumed the responsibility of navigating the LIGHTSAT program through a bureaucratic morass.

The technical director of the Naval Space Command and one of the foremost leaders in providing sound arguments for a small satellite capability, Mr. William E. Howard, strongly supports DARPA's direction. Howard feels that DARPA funding of the LIGHTSAT program is critical to the services because until the technology is proved to be capable, the services will be extremely hesitant to fund such a high risk effort (16:4). Howard feels as if lightweight satellites could evolve into hardware similar to

tanks and ships (16:1). And that is exactly how the individual services would treat LIGHTSATs - as affordable assets that are capable of providing vital space derived information. The uses of LIGHTSAT would possibly include imagery resolution, store and forward communications and target detection. Howard further argues that through a balance of strategic and tactical (LIGHTSAT) satellites, the military would greatly benefit. Current problems of survivability and reconstitution would be reduced and operational commanders could begin to develop new ways to use LIGHTSATs as force multipliers (15:1). Mr. Howard has perhaps stated the requirements shortfall with current satellite systems in the most succinct terms. Existing systems possess some of the following problems:

1. Lack of timely feedback from data collection.
2. Difficulties in getting tasking priority.
3. Perception of a lack of survivability.
4. Problems in reconstitution. (16:1)

Howard puts forth 3 scenarios in which existing satellite systems would likely encounter problems. The first scenario is one where a crisis situation is not within our control. Due to this situation, there will probably be low priority in tasking for the operational commanders as the national leadership seek to gain as much information about the crisis as is possible. The second one, envisions a low satellite system capacity because of multiple hotspots

around the world. The current systems would be significantly overburdened by the need of our national leadeship to gain intelligence over wide areas of the globe very quickly. The last scenario forecasts a very high intensity of conflict. This would likely make our satellites a target of high value to attack (16:1). It is this rationale that enables Howard to call for a LIGHTSAT type system to complement our existing and very capable satellite systems.

Another concern that LIGHTSAT proponents address is that U.S. space facilities are extremely vulnerable to enemy countermeasures in wartime. Dr. Mansfield expressed concern about the vulnerability of U.S. launch facilities to Soviet actions. Mansfield develops a scenario whereby, in times of conflict, Soviet leaders decide to eliminate our satellites with their anti-satellite (ASAT) capability and then destroy our launch facilities. Within such a scenario, the U.S. would have only a very limited response capability before escalating to nuclear warfare. The LIGHTSAT capability addresses this vulnerability, as small satellites could be launched out of ICBM silos, submarines, mobile ground launchers and possibly even aircraft (25:65).

LIGHTSATs really mean an affordable system of satellites, launchers and ground support network. Opponents of LIGHTSAT are critical of the idea that LIGHTSAT is indeed

low-cost and affordable. In fact, Mr. Donohue (DARPA's director of the ASTP program) has stated that LIGHTSATs will probably not be cheap (8). Ultimately, LIGHTSAT advocates must address the questions of total cost and increased capability.

It is estimated that overall cost can indeed be brought considerably lower. ANSER, an independent research corporation, reported that satellite costs of under $10,000 per pound could be achieved. With the current cost of approximately $80,000 per pound this is almost an order of magnitude reduction in cost for satellite development (2:3-4).

DARPA is also considering supporting development of several new types of boosters to launch small satellites. The goal is to develop a more cost-effective standard small launch vehicle (25:65). As for launch vehicles, the current cost for a Scout launch vehicle (capable of carrying to low earth orbit a 570 pound payload) is approximately $10 million. Another concept is the air-launching of satellites from aircraft. One concept, called Pegasus (developed by Orbital Sciences Corporation), will launch satellites from a B-52 aircraft. This is forecasted to cost between $7,000-$8,000 per pound (11:20) or approximately $5-$6 million per satellite launch.

Perhaps the difference between LIGHTSAT proponents and opponents can be described as an intrusion on Air Force responsibility of space development by DARPA. Based upon their newly acquired prototyping mission, DARPA's technology push is a dramatic change from the standard technology pull associated with military hardware development. It is quite possibly this change that has caused widespread opposition from key Air Force leadership (5:2).

Another possible explanation for Air Force opposition to the LIGHTSAT program can be traced to the Air Force's "desire to maintain control of classified space reconnaissance programs" (20:2). Due to constrained budgets and competing priorities, there may exist a fear that LIGHTSAT may jeopardize the funding for these national programs (20:2).

Although there are many opponents to the LIGHTSAT program, Air Force Secretary Edward C. Aldridge is the most outspoken and respected opponent. Secretary Aldridge is well known for his position against sole reliance on the space shuttle as a method for space transportation while advocating expendable launch vehicles (ELV's). The Challenger accident in 1986 further reinforced Secretary Aldridge's excellent reputation in the space arena due to his support of ELV's. At the Fourth National Space Symposium (April of 1988), Secretary Aldridge stated that

the nation should rely solely on expensive, long-life and multi-purpose satellites (32:3). This stand seems to be in marked contrast to his earlier philosophy of diversifying within a mission area. He has consistently argued against the LIGHTSAT concept, stating that these inexpensive systems fail to possess the required availability and reliability needed for current and future military needs (32:3). Aldridge further stated, "Let's not take our technological advantage and, through an untested change in philosophy, turn it into an operational weakness" (32:3).

Another key point in Aldridge's argument against the LIGHTSAT program is that military commanders do not have simple and inexpensive requirements but rather highly, sophisticated needs which cannot be met by the LIGHTSAT concept. Field commanders insist upon 24 hour continuous coverage in their theater of responsibility which means that the number of light satellites may well be in the hundreds (31:29).

Secretary Aldridge's position on LIGHTSAT has softened somewhat. In September of 1988, he stated that he is not against small satellite research, but he still claims that operational commanders cannot meet their requirements with small, inexpensive satellites (11:20).

Mr. Donald Latham, former Assistant Secretary of Defense for Command, Control, Communications and

Intelligence (C3I) for approximately 6 years in the Reagan administration also lends considerable credibility to the argument against the LIGHTSAT concept. Latham argues that the Army and Navy have been deluded by LIGHTSAT proponents proclaiming unrealistic expectations (18:38). Disputing the fact that large, national satellite programs cannot support the tactical commander, Latham states "MILSTAR will serve all tactical and strategic users down to low echelons of command, be they mobile or fixed" (18:38). Latham also argues that existing satellite systems are survivable at all levels of conflict (18:38-39).

Former Deputy Director of the Central Intelligence Agency and presently a Group Executive Vice President for Lockheed Missiles and Space Company, John McMahon cautions:

> The military commander has too many needs to be satisfied in toto by a lightweight system. But what LIGHTSATs can do is fill a void in information ... LIGHTSATs can offload some of the requirements on other systems. (18:42)

The cost of LIGHTSAT involves not just the satellite cost but also includes the required ground support network for information processing and ground control, launch vehicles to be able to place large constellations in orbit and systems to ensure reliable operations and replacement (31:29). Mr. Chester Whitehair, architecture planning and technology division general manager for Aerospace Corp.,

stated that the satellite systems of today evolved from smaller satellites due to increasing military requirements for greater reliability, redundancy and survivability. Whitehair further stated that the low orbital altitudes normally required of LIGHTSAT constellations also require more satellites (at least an order of magnitude greater) due to the satellites limited coverage. The constellations of small satellites would also be more vulnerable to radiation from nuclear detonations and laser damage (9:28).

Launcher costs currently are a much greater expense than light satellite costs. Until these costs can be adequately matched, it is not economically feasible to use the LIGHTSAT concept. "Either the sophistication of the satellite should increase to match the price of the launcher, or the launcher costs needs to be lowered" (9:28). Mr. James French, a space consultant at JRF Engineering Services, has stated that if LIGHTSAT costs are in the range of $2 - $4 million a copy (as many LIGHTSAT advocates say), launch costs must be reduced to approximately $5 -$8 milliom per satellite. Right now, only the small Scout launch vehicle is operational for light satelite payloads and the cost is about $15 million (12:16). This claim is 50% higher than ANSER proposed. In addition to launcher costs, the current cost of ground terminals are far too expensive to match the simplicity and low-cost of the light satellites (9:28).

Joint Surveillance Target Attack Radar

The current program is a joint effort between the Army and the Air Force that originated in 1982. The concept behind the Joint Surveillance Target Attack Radar (JSTARS) is to provide real time intelligence information to the Corps commander by way of surveillance, tracking, detecting and classifying targets on the battlefield. Considered a key part of Air-Land Battle doctrine, defense leadership envisions JSTARS providing the critical intelligence information necessary to allow theater commanders to attack Soviet follow-on forces with long range artillery, air strikes and quite possibly maneuver forces. The Army program manager in 1986, Col. G. Sidney Smith Jr.,said, "The Army sees Joint STARS as the key piece that will allow commanders to manage the battle" (3:77).

It is estimated that JSTARS will cost at least $4 billion and is scheduled to be fielded in the 1992-1995 period. The system, designated E-8A is an airborne multi-mode radar with associated communications that is mounted on a converted Boeing 707-320 aircraft. Mobile ground stations would receive the raw data to process into information (21:1188).

The E-8A would fly a circular pattern at an altitude of 33,000 to 40,000 feet and approximately 100 kilometers behind the forward line of troops (FLOT). For 24 hour

coverage, three E-8A's would be needed without any in-flight refueling. JSTARS will have an all weather, day-night, wide area coverage capability (21:1189).

Problems with JSTARS have been reported in the development of the radar, the survivability of the aircraft and the cost. Charges that JSTARS will be vulnerable to Soviet anti-aircraft missiles, jamming and fighters have drawn much attention. However, defense officials contend that JSTARS is not only capable but survivable. Consideration of incorporating stealth technology into future JSTARS is also a possibility (21:1191).

Conclusions

It is clear that the LIGHTSAT program is a controversial issue. There is clear cut opposition from the more traditonal satellite communities - the Air Force and much of industry. However, there are many proponents that seek a change in the traditional satellite thinking. Military decision-makers are faced with decisons that need to be made soon in order to have these systems operational in the mid 1990's. Complicating these difficult decisions are evolving satellite capabilities and weapon technologies with uncertainty and risk (14:1). With a tight federal and defense budget looming over the nation's head, it seems only logical that additional study be given to the LIGHTSAT issue to see if it is a cost-effective system. If LIGHTSAT does

prove to be a cost effective system, military doctrine might vey well be revolutionized.

In facing this strategic decision, Army leadership must answer these questions in its quest for an increased world-wide combat capability. There will be several alternatives that the Army may be able to choose from. But there will also be a significant risk factor involved based upon the uncertainty of the situation.

## III. Decision Analysis Methodology

Within the scope of this chapter, the framework of the decision analysis cycle will described. The definitions of reconnaissance (R), surveillance (S) and target acquisition (TA) will serve as a starting point for this methodology. The alternatives facing the decision maker will follow the definitions. Then the influence diagram for this decision will illustrate the key elements and relationships of this decision. Units of measurement and measures of effectiveness by which to measure each alternative will follow and be discussed in detail. The value function which establishes the outcomes for each alternative will then be discussed. The method by which the levels of R, S and TA are determined and how each variable relates to the value function will then be presented. The decision analysis methodology, by which the problem can be evaluated, will conclude the chapter.

Senior Army leaders are faced with a decision of whether to procure a potentially high risk but high payoff satellite system to meet battlefield RSTA needs. The choice of whether to go ahead with LIGHTSAT development and deployment is a multi-dimensioned problem loaded with uncertainty, risk and potentially high payoff.

As with most problems, formulation of the problem is often time consuming and difficult. Prior to searching for solutions, the relationships between all the variables must be understood fully. The formulation of the value model is another challenging task of the problem. Value modeling, although very difficult, is the heart of decision analysis. Faced with multiple alternatives and outcomes, the decision maker must be able to distinguish how well one alternative performs compared to other alternatives. It is the value model that allows the decision maker to perform this distinction.

## Definitions

Reconnaissance. The ability to detect, locate and classify specific targets or information within a specific area of the battlefield. For example, reconnaissance is the active pursuit of information pertaining to a specific motorized rifle division.

Surveillance. The ability to detect, locate and classify targets across the entire width and depth of the battlefield. The passive, systematic watching or listening for air defense radars to cue is an example of surveillance.

Target Acquisition. The ability to detect, locate and classify targets to a desired accuracy that available weapons systems can effectively engage the targets. An example of this would be the detection, location and

classification of a command and contol headquarters to 100 meters accuracy. This detailed identification would enable artillery, missiles or aircraft to attack the target and expect a successful outcome. In moving from the general to the more specific, the order of these capabilities would be surveillance, reconnaissance and then target acquisition.

## Alternatives

Due to the unclassified nature of this problem, many of the alternatives are not considered. However, it is felt that the same approach could be used with all available alternatives. The alternatives used in this study are:

ALT 1 - LIGHTSAT

ALT 2 - JSTARS

LIGHTSATs are small, lightweight, single purpose and inexpensive satellites. The U.S. Army is looking into the possibility of using LIGHTSATs to enhance their combat capabilities in the intelligence arena.

JSTARS is an E-8A aircraft with an airborne multimode radar that is designed to provide battlefield surveillance and targeting data to the battlefield commanders.

For greater detail on these two alternatives, refer to Chapter 2.

## Influence Diagram

In order to fully understand this problem an influence diagram is used. The intent of the influence diagram is to

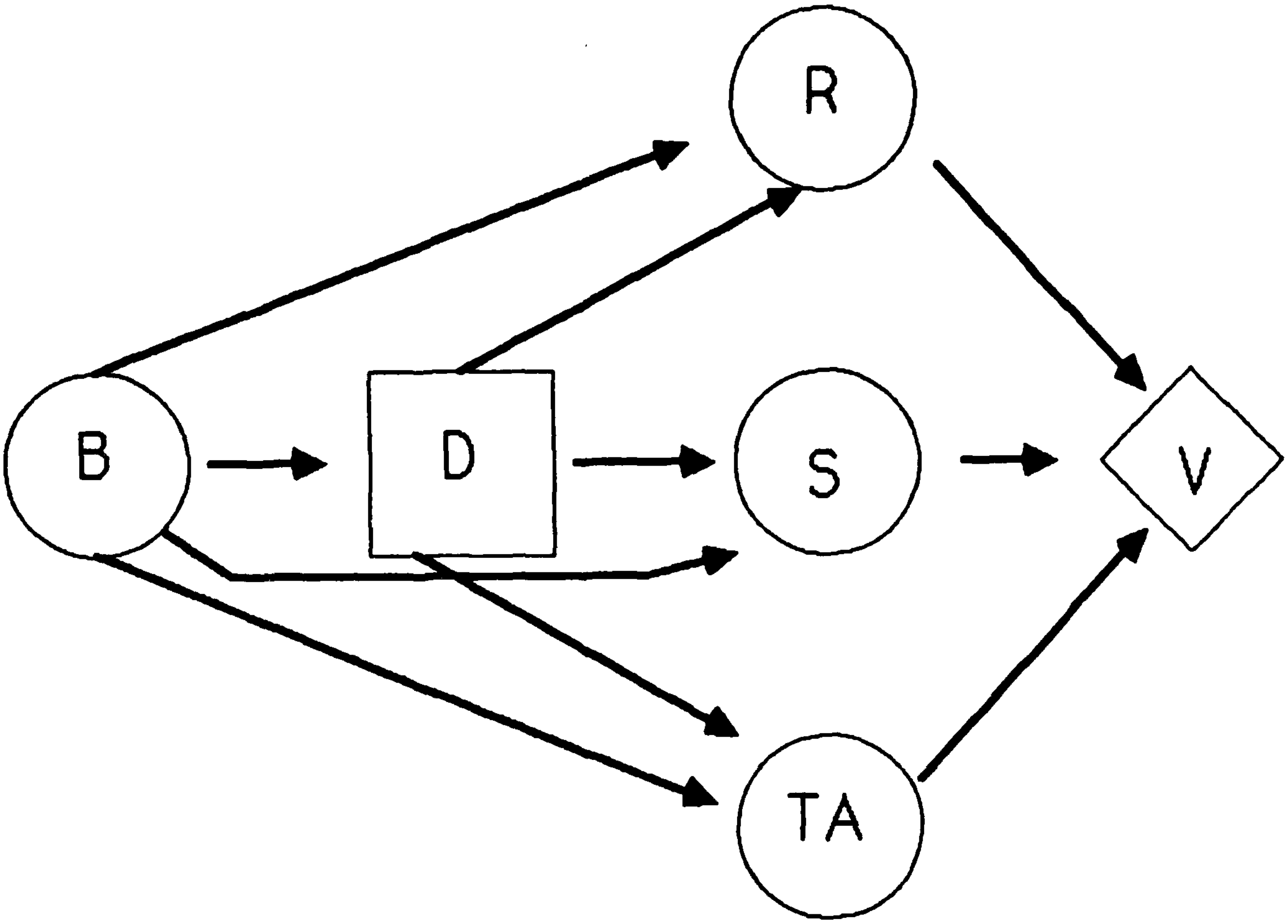
portray to the decision maker the dependencies that exist among the variables in the problem and the availability of information to the decision maker (29:2).

The approach taken in this chapter is that there is a fixed budget for RSTA. Whatever increased capabilities are needed to assist the battlefield commander will come out of this limited budget.

The influence diagram for this problem (Figure 1) clearly identifies the dependencies within the problem. The decision, should the Army procure LIGHTSAT for battlefield RSTA missions, is based upon the amount of information available to the decision maker concerning the budget. The levels of each of the RSTA missions, reconnaissance (R), surveillance (S) and target acquisition (TA) that are achieved are a result of the decision and the level of the budget. Finally, the overall value function (described in detail later), is composed of a combination of the nodes R, S, and TA.

Units of Measurement

Units of measurement, by which the alternatives will be evaluated, must be well defined and natural for the decision-maker. A theatre commander would probably rather think in terms of tank battalions than dollars. The value for each of the alternatives must be expressed in common units or else comparision between choices becomes more




B = Budget
D = Decision
R = Reconnaissance
S = Surveillance
TA = Target Acquisition
V = Value

Figure 1. Influence Diagram

difficult. For example, alternatives A, B and D cannot be expressed in dollars and alternative C expressed in human lives.

For this study, the units of measurement that will be used are M-1 tanks. This unit of measurement can easily be translated into dollars, if need be.

Measures of Effectiveness

Before any decision can be made, measures of effectiveness (MOE's) must be developed in order to evaluate each course of action. The MOE's chosen must be able to withstand scrutiny from both the analytic and operational communities. The MOE's must be fully defined in order that a single numerical value assigned to each MOE is completely understood. This is often referred to as passing the clarity test in decision analysis.

Each of the areas of RSTA will be broken down and assigned a separate MOE. The MOE for reconnaissance is defined as the increased level of critical targets/targets of value (designated by the commander) within a specified area of the battlefield that are located and transmitted to the theater commander within 60 minutes over a seven day period (average).

The surveillance MOE is defined as the increased level of critical targets/targets of value (designated by the commander) over the entire battlefield that are located and

transmitted back to the theater commander within 60 minutes over a seven day period (average). As defined earlier, surveillance is passive while reconnaissance is an active form of intelligence gathering.

The MOE for target acquisition will be the increased level of critical targets/targets of value that are located and transmitted to the theater commander within 10 minutes over a seven day period (average).

Although the MOE's are similar, it is important to note that the MOE for target acquisition is more restrictive (10 minutes vs 60 minutes) due to the importance of the perishability of information on the battlefield (24). A major problem facing operational planners is that intelligence data is sometimes of minimal value. The reason for this is that many targets change their locations quickly in order to ensure survivability on the battlefield. By the time that targeting data reaches the appropriate level of command by which to engage the target, the target has relocated. This results in the expenditure of valuable ammunition and often risks lives unnecessarily. This is the primary reason why the target acquisition MOE is more constrained in nature.

There may be other MOE's for R, S, and TA besides the ones described above. However, from an operational perspective, these MOE's can be considered realistic and

sensible based upon personal experience and conversations with other military officers.

In order to go forward with development and deployment of a new system, a measurable and positive change in performance must be realized. This is exactly what the MOE's seek to identify. Another critical factor, the transmission of that information back to the commander must be met consistently. A system that produces an increase in locating targets but fails to get this information back to the commander in a timely manner does not contribute a great deal to creating a combat advantage. Operational commanders demand fully responsive systems.

In addition, not all targets are vital to the commander. Only those targets that the commander deems critical to the mission must be located. For instance, locating all transport trucks within a specific area does not aid the commander's planning ability as greatly as would locating all air-defense radars, command, control and communication (C3) centers or tank formations of a certain size. The theatre commander should also have the ability to shift target emphasis from one type of target to another.

From an analytical view, these MOE's are difficult to measure. Targets on the battlefield have varying degrees of value depending on where they are located, the current operational situation and many other factors. A very

detailed and extensive model that accurately depicts these factors would need to be developed and analyzed. To the extent of this unclassified research, a model of this type does not exist.

For the intent of this study, the definitions and the values of the MOE's will be assumed based upon personal experience and the interviews of Army and Air Force officers.

Now that the measures of effectiveness have been developed, the next key element of the methodology that will be discussed is the value function.

## Value Function

Ideally, the value function would be developed by questionning the decision maker in a thorough manner. This process would reveal the exact values of the decision maker for each possible alternative and outcome. The ultimate decision maker in this problem is the Chief of Staff of the Army. If direct assessment cannot be accomplished, then the value function must be developed based upon experts at lower levels. Even if direct assessment is possible, the decision maker may still wish for a value function to be developed by experts at lower levels as a check for consistency. Direct assessment was not practical for this study.

The value function for this study is not based upon any existing analytical model but is formed from interviews with

combat arms company grade officers and a field grade Air Force pilot who are operationally familiar with Air-Land Battle doctrine in the Central European theater. The value model is not a simple linear function due to the interdependencies of R, S, and TA. The overall value function is not of the form

$$V = xR + yS + zTA$$

$$x,\ y,\ z \rightarrow \text{constants}$$

The reality of the situation is that R, S, and TA are interrelated to a such a degree that without making any assumptions of linearity, a value function must be derived. The level of surveillance data affects the importance of reconnaissance to the commander. For example, if surveillance data reveals that there is a build up of tank forces 250 kilometers beyond the forward line of troops (FLOT), a commander might want to request reconnaissance information about all bridges between the enemy concentration and the FLOT. This would then allow the commander to initiate plans for impeding the advance of the tank forces. Similarly, TA data allows the commander to develop order of battle plans which would allow commanders to develop specific reconnaissance plans.

Methodology. The value function was derived through controlled interviews that used the following scenario. As a theater commander in Central Europe, you have

approximately 45-55 tank battalions (M1's) under your control. You are currently at peace but there is a good probability that war will break out within a year. Your current RSTA capabilities are:

R -> .4
S -> .33
TA -> .2

For example, you can currently detect, locate and classify 4 out of every 10 critical targets on the battlefield in the reconnaissance mission. The following question was then posed. How many M-1 tank battalions would you be willing to trade for an increase in your ability to detect, locate and classify the enemy in a more timely and accurate manner? The current and increased RSTA capabilities (low and high) postulated were as follows:

Table 1. Summary of RSTA Capabilities

| | CURRENT | NEW LOW | NEW HIGH |
|---|---|---|---|
| R | .4 | .45 | .75 |
| S | .33 | .4 | .6 |
| TA | .2 | .25 | .4 |

To demonstrate the interdependencies of R, S and TA, various situational capabilities of RSTA were used and are shown in the Table 2 on the following page.

Table 2. RSTA Parameters & Values

| R | S | TA | # TANK BATTALIONS TRADED #1 | #2 | #3 | #4 |
|---|---|---|---|---|---|---|
| LO | LO | LO | .5 | 1.0 | .5 | 1.0 |
| LO | LO | HI | 4.0 | 2.0 | 2.0 | 1.5 |
| LO | HI | LO | 2.0 | 2.5 | .5 | 1.5 |
| HI | LO | LO | 4.0 | 3.0 | 1.0 | 1.5 |
| HI | HI | LO | 5.0 | 4.75 | 1.2 | 1.5 |
| HI | LO | HI | 5.5 | 4.0 | 2.4 | 2.5 |
| LO | HI | HI | 4.5 | 3.5 | 2.2 | 2.0 |
| HI | HI | HI | 6.0 | 5.0 | 3.0 | 3.0 |

In response to the scenario of a change of R, S and TA from current capabilities to high capabilities (last line of the chart - hi, hi, hi), the first individual that was interviewed was willing to trade 6 battalions of tanks for this increased capability. Individuals 2, 3 and 4 were willing to trade 5, 3 and 3 tank battalions, respectively.

Multiple linear regression was used to find a surface that best fit the above data. The model depicting the relationships of R, S and TA was:

$$V = -7.89\ RT - 5.17\ ST + 7.16\ R + 5.32\ S + 16.3\ T - 7.23$$

With this function and the values of R, S and TA, the overall value in battalions of tanks that a given RSTA system would be worth to a theater commander can be obtained. Several examples of how this function would work are depicted below.

Table 3. Illustration of Value Function with Sample Data

| R | S | TA | V |
|---|---|---|---|
| .48 | .42 | .29 | 1.44 |
| .65 | .55 | .40 | 3.68 |
| .80 | .75 | .50 | 5.54 |

Given that the following levels of R, S and TA could be achieved, the overall value to the decision maker would be 1.44, 3.68 and 5.54 battalions of tanks. The graph of this function would be four dimensional and is not shown in this study.

The value function has been developed and V has been shown to be dependent upon the variables R, S and TA. The variables R, S and TA require a method or model by which they can be now be arrived at.

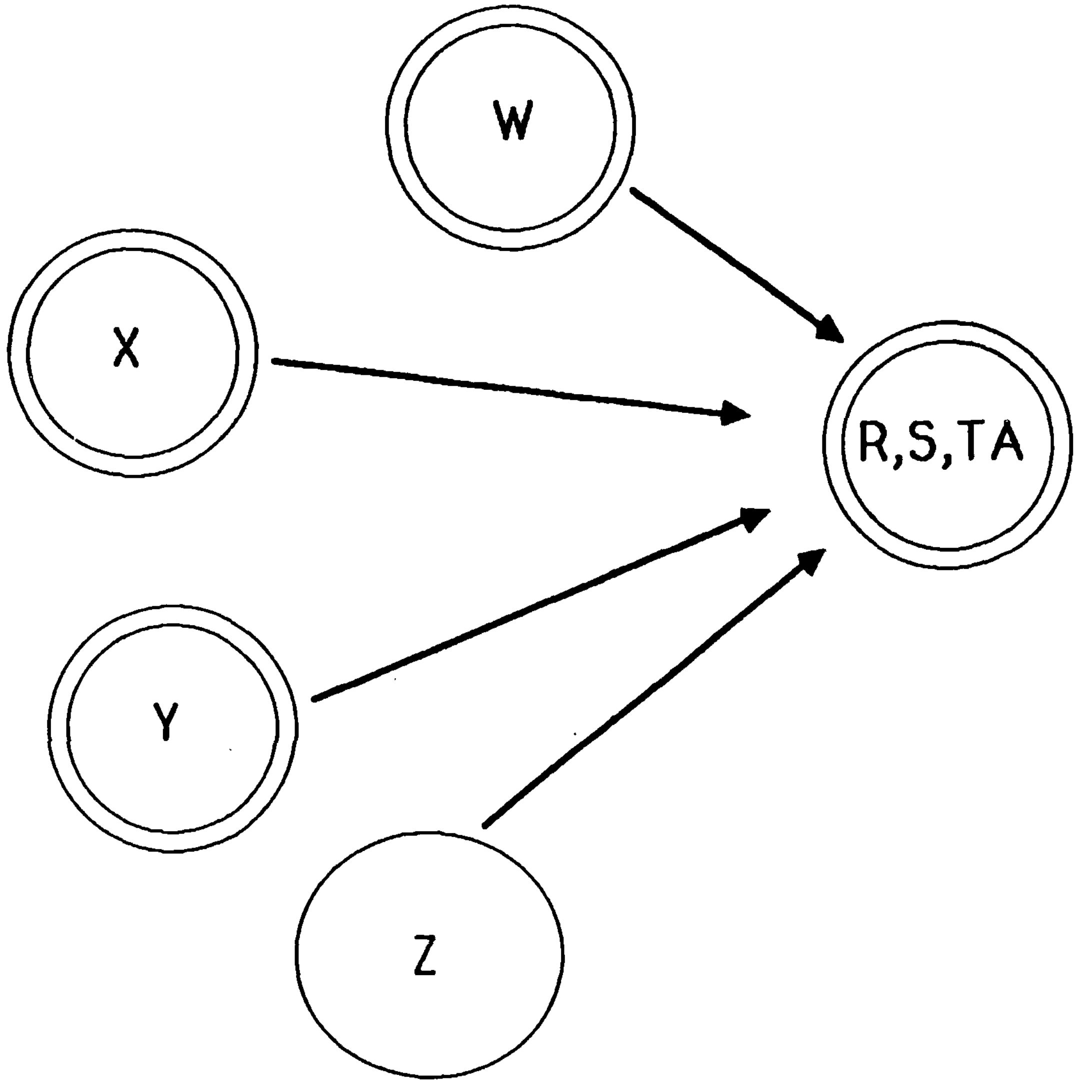
Determining R, S and TA

If the levels of R, S and TA can be arrived at then an overall value for the outcome for each alternative can be determined. In trying to answer the question, what affects R, S and TA, Figure 2 depicts an initial attempt to define that relationship.

The variables W, X, Y and Z represent the four independent factors that influence the actual level of R, S and TA, respectively.

For the purpose of this study, the levels of R, S and TA are considered dependent upon the following:

1. Percent of targets on the battlefield that are within the range of the RSTA system (W).
2. Percent of targets that cannot be located by current RSTA methods (X).
3. Percent of targets that are capable of being identified when the system is fully operational (Y).
4. Percent capability of the system after a percent of the system (0%, 20% and 40%) is countermeasured (Z).




W - % Targets within range of RSTA System
X - % Targets not currently located
Y - % Targets located at system's full capability
Z - % System capability after enemy CM

◎ - Deterministic Variable ○ - Random Variable

Figure 2. Factors Affecting R, S and TA

$$R = W * X * Y * Z$$
(same for S and TA)

The percent of operational capability remaining after enemy countermeasures are undertaken is an unknown because the type and intensity of countermeasures that the enemy will take is unknown. W, X and Y are considered constant for this study. The values for W, X and Y can be found in Figures 3 through 10. This data is assumed based upon experience in order to demonstrate the methodology.

Figures 3 through 8 yield the values for the variable Y. Figure 9 depicts the value for W and Figure 10 represents the value for Z.

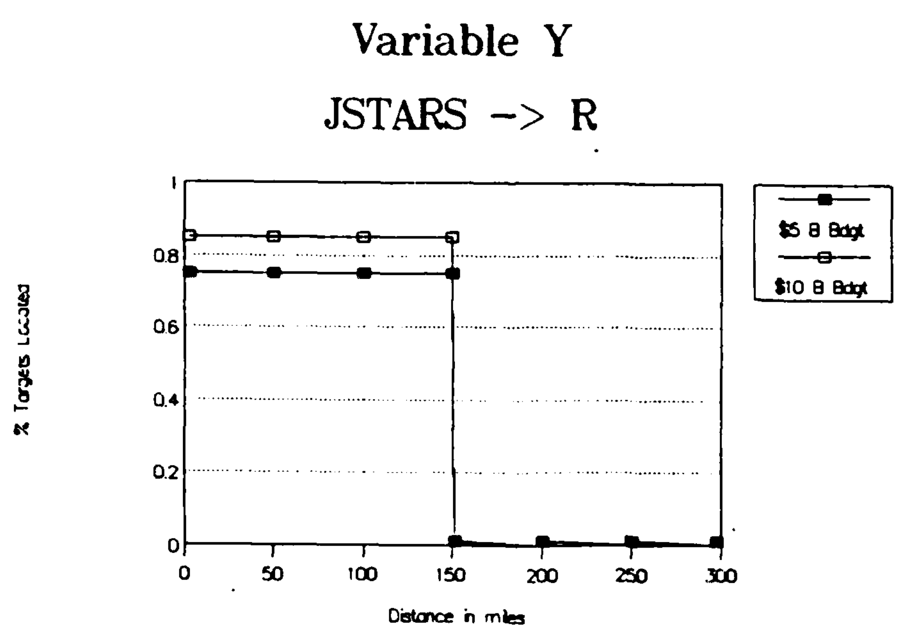



Figure 3. % of Targets Located by JSTARS for R

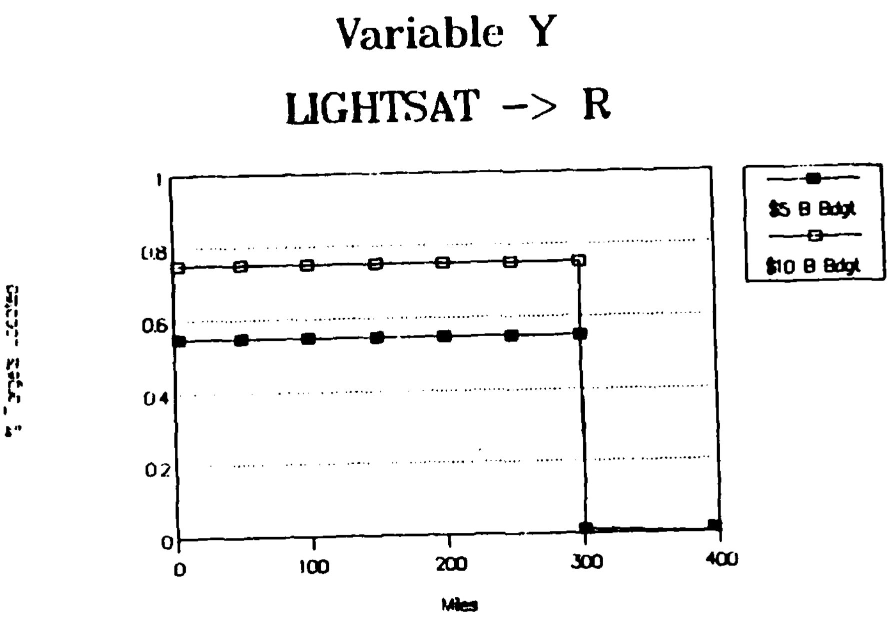



Figure 4. % of Targets Located by LIGHTSAT for R

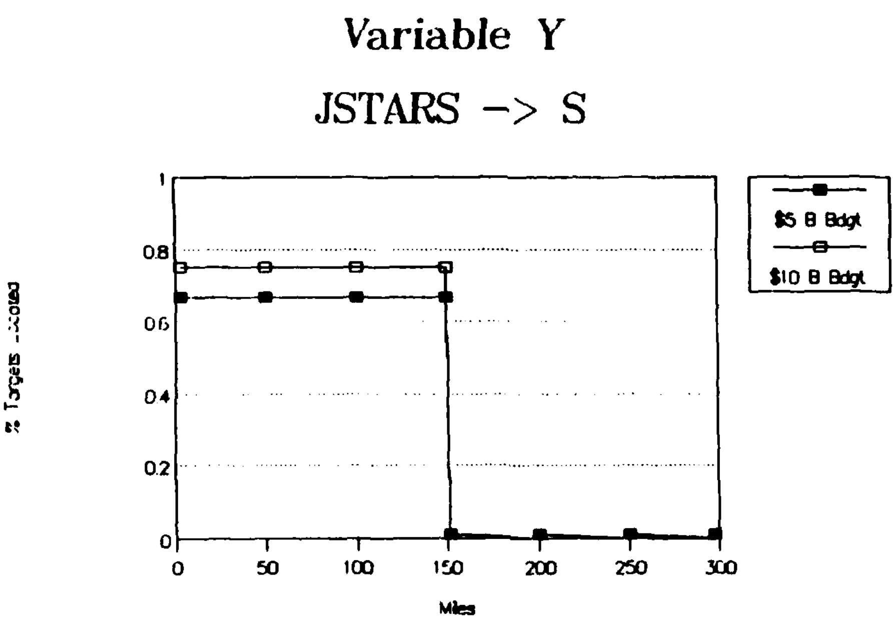



Figure 5. % of Targets Located by JSTARS for S

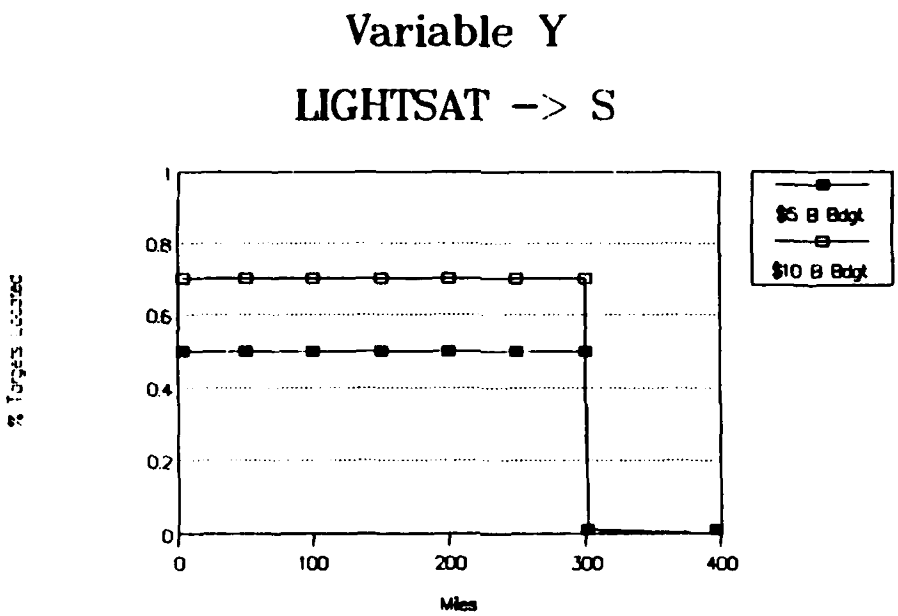



Figure 6. % of Targets Located by LIGHTSAT for S

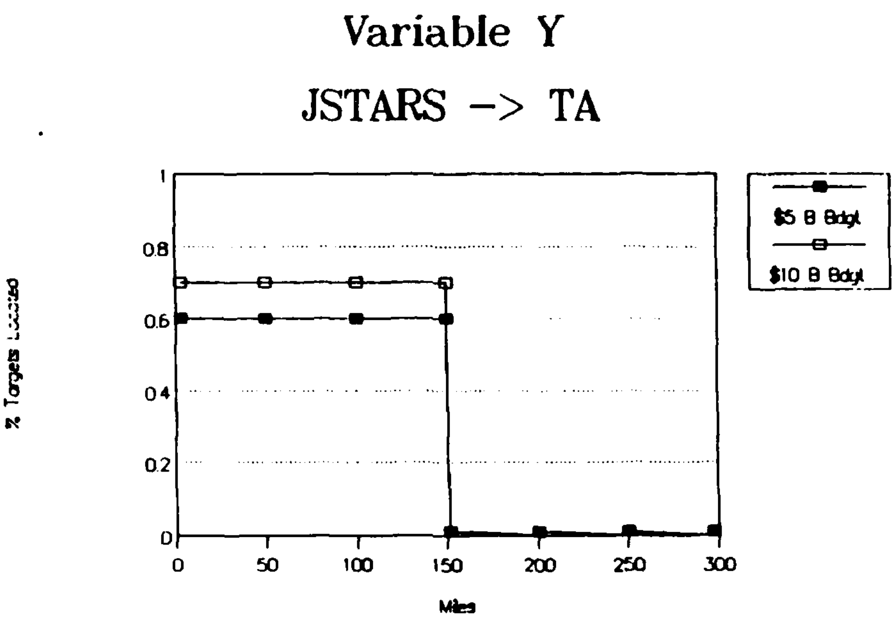



Figure 7. % of Targets Located by JSTARS for TA

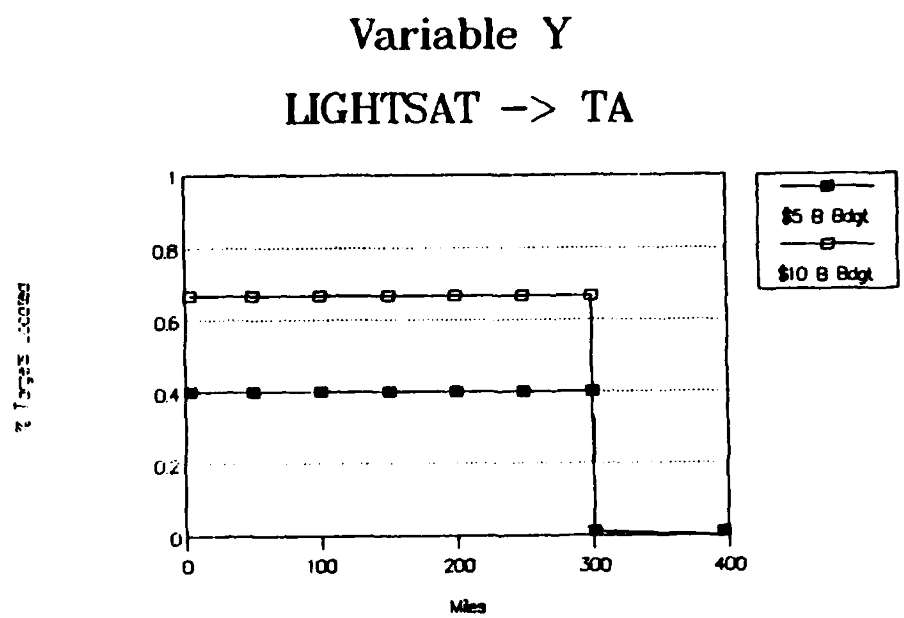



Figure 8. % of Targets Located by LIGHTSAT for TA

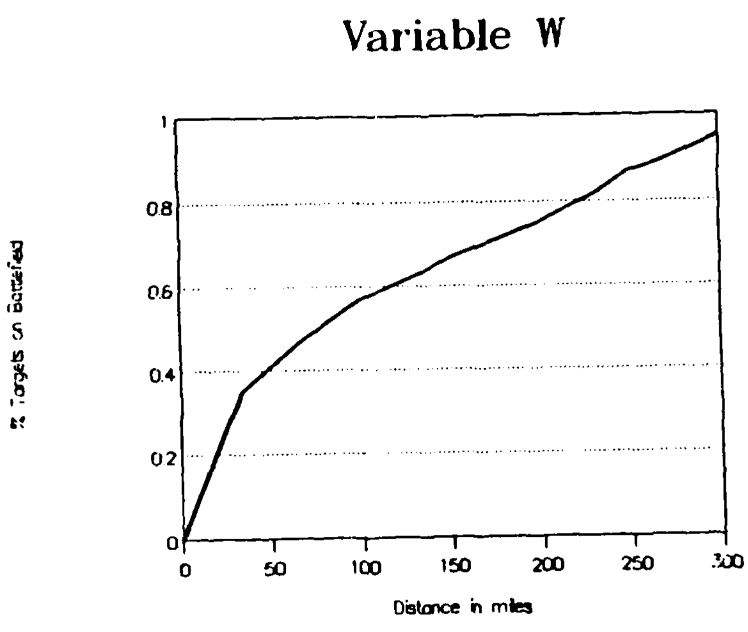



Figure 9. % of Targets by Distance on the Battlefield

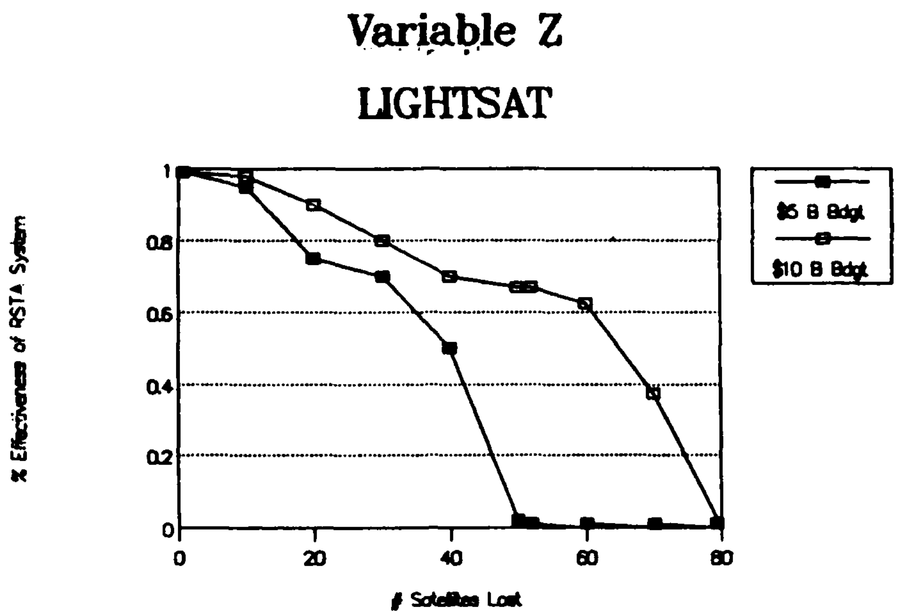



Figure 10. % Effectiveness when System is Fully Operational

The data required for determining the increased levels of R, S and TA can be found in Figures 3 through 10. A summary of the calculated levels of R, S and TA are found in Tables 4 and 5.

Table 4. Summary of RSTA Levels for JSTARS
(Budget = $5 billion)

| | W<br>% tgts w/in 150 miles | X<br>% tgts not currently located | Y<br>% tgts located full cap | Z@<br>% cap after CM | current level | new level |
|---|---|---|---|---|---|---|
| R | .667 | .6 | .75 | .98 | .4 | .694 |
| | .667 | .6 | .75 | .96 | .4 | .688 |
| | .667 | .6 | .75 | .88 | .4 | .664 |
| S | .667 | .667 | .667 | .98 | .33 | .621 |
| | .667 | .667 | .667 | .96 | .33 | .615 |
| | .667 | .667 | .667 | .88 | .33 | .591 |
| TA | .667 | .8 | .6 | .98 | .2 | .515 |
| | .667 | .8 | .6 | .96 | .2 | .509 |
| | .667 | .8 | .6 | .88 | .2 | .483 |

@ (22:40)

Table 5. Summary of RSTA Levels for LIGHTSAT
(Budget = $5 billion)

| | W<br>% tgts w/in 300 miles | X<br>% tgts not currently located | Y<br>% tgts located full cap | Z<br>% cap after CM | current level | new level |
|---|---|---|---|---|---|---|
| R | .95 | .6 | .55 | 1.0 | .4 | .713 |
| | .95 | .6 | .55 | .85 | .4 | .666 |
| | .95 | .6 | .55 | .75 | .4 | .635 |
| S | .95 | .667 | .5 | 1.0 | .33 | .647 |
| | .95 | .667 | .5 | .85 | .33 | .599 |
| | .95 | .667 | .5 | .75 | .33 | .568 |
| TA | .95 | .8 | .4 | 1.0 | .2 | .504 |
| | .95 | .8 | .4 | .85 | .2 | .458 |
| | .95 | .8 | .4 | .75 | .2 | .428 |

Appendix B contains the data for the RSTA levels for both LIGHTSAT and JSTARS for a $10 billion budget.

When the data from Tables 4 and 5 are combined with the value function that was derived earlier (see page 32), values can be computed for each alternative. These values are in units of battalions of M-1 tanks.

Table 6 shows the increased levels of R, S and TA and the respective values for each system.

Table 6. Value Summary

| System | Budget | R | S | TA | Value |
|---|---|---|---|---|---|
| JSTARS | $5 B | .694 | .621 | .515 | 4.96 |
| JSTARS | $5 B | .688 | .615 | .509 | 4.88 |
| JSTARS | $5 B | .664 | .591 | .483 | 4.53 |
| LIGHTSAT | $5 B | .713 | .647 | .504 | 5.01 |
| LIGHTSAT | $5 B | .666 | .599 | .488 | 4.36 |
| LIGHTSAT | $5 B | .635 | .568 | .428 | 3.91 |
| JSTARS | $10 B | .737 | .660 | .570 | 5.59 |
| JSTARS | $10 B | .733 | .657 | .566 | 5.54 |
| JSTARS | $10 B | .723 | .647 | .555 | 5.41 |
| LIGHTSAT | $10 B | .827 | .774 | .707 | 6.89 |
| LIGHTSAT | $10 B | .806 | .751 | .682 | 6.67 |
| LIGHTSAT | $10 B | .721 | .663 | .580 | 5.63 |

A JSTARS system at the $5 billion budget level, with R, S and TA values as shown above (computed in Table 4), would be worth between 4.53 and 4.96 battalions of M-1 tanks to the decision maker. The variation in the value is due to the uncertainty in the system's capability based on the enemy's countermeasures. This is the only factor in this study that was considered a random variable.

## Probability Assessment

Based upon the assumptions made in this study, the percent of enemy countermeasures directed against the RSTA system must be determined. As this assessment is highly classified, the probability for variable Z for JSTARS was based upon a Rand study of JSTARS effectiveness (22:40) and the LIGHTSAT probability was assumed.

## Decision Tree

The structure of the problem, seen in Figure 11, can now be solved for expected value. A launch to orbit cost of $31.9 million was assumed based upon data from the U.S. Army Space Institute (10). Based on a $5 billion budget and a launch to orbit cost of $31.9 million for LIGHTSAT, 152 LIGHTSATs could be procured over a 10 year period. Since it was assumed that LIGHTSAT had a lifespan of 3.33 years, only 52 LIGHTSATs were available for coverage of Central Europe at one time. The $5 billion budget would also allow for 5 Corps orbits with 5 aircraft in each orbit. Probabilities

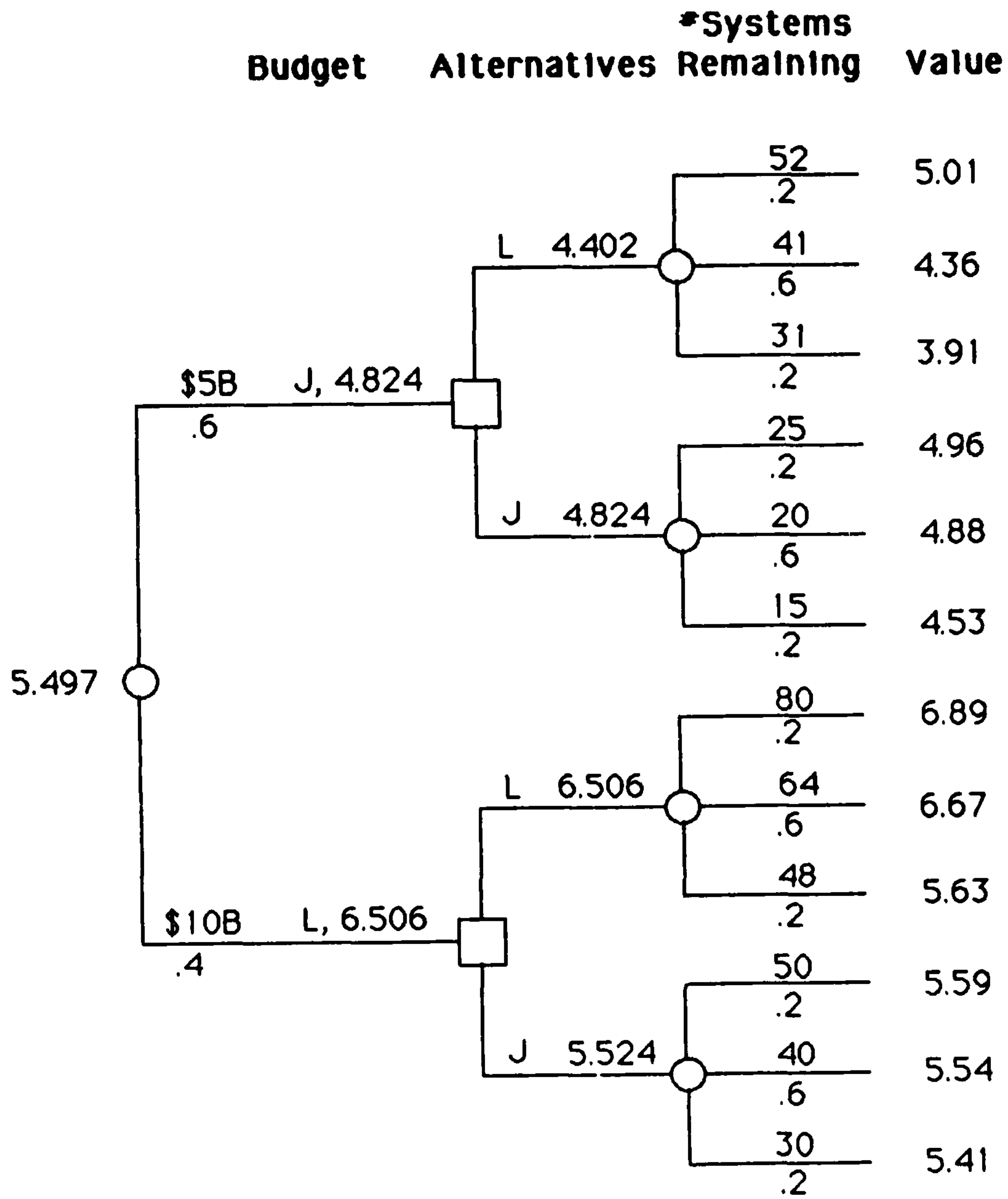



Figure 11. Decision Tree for Known Budget Levels and Unknown Levels of CM

for varying levels of enemy countermeasures and for the different budget levels were assumed.

Taking the expected values, at the $5 billion budget decision, JSTARS possessed a higher value than LIGHTSAT - 4.824 to 4.402 battalions of M-1 tanks. At the $10 billion budget decision, LIGHTSAT had a value of 6.506 tank battalions to a value of 5.524 tank battalions for JSTARS. From this analysis, the decision that should be made is strongly dependent upon how much funding is available for the RSTA system.

If the decision maker did not know the level of the budget the structure of the problem would look like Figure 12. The decision would be to choose LIGHTSAT over JSTARS due to a higher value, 5.244 to 5.104.

Due to the uncertain nature of the information in this study, the decision maker may want to invest some additional funds into determining the nature of either the budget level or the level of enemy countermeasures. This is known as the value of information. If the information gained is perfect, there is no uncertainty about its validity, then the expected value of perfect information can be found by taking the difference between the value of the decision without information and the value of the decision when perfect information is introduced. EVPI for the budget level would be found by taking the difference in expected values from

Figures 11 and 12. The EVPI for the budget is .253 battalions of tanks. If a tank battalion is assumed to cost $162 million (1 tank = $3 million and 1 tank battalion = 54 tanks), then EVPI for the budget level would be $41.02 million. The decision maker would be willing to pay $41.02 million to have perfect information on the budget level but nothing greater.

Similarly, EVPI for enemy countermeasures can be done. Taking the difference in exxpected values from Figures 12 and 13, the value for EVPI would be .113 battalions of tanks or $18.33 million.

Translating EVPI into actions would indicate that the Army would be willing to allocate up to the limit of EVPI to reduce the uncertainty of the decision. For example, additional funding of intelligence collection for determining the extent of enemy countermeasures would not exceed $18.33 million. The same reasoning would be true for studying the exactness of the budget, no more than $41.02 million would be spent.

## Summary

This chapter has attempted to analyze the difficult decision facing senior Army leadership concerning LIGHTSAT and the need for a RSTA system to support the battlefield commander. The decision analysis methodology has been explored within the context of this decision. This

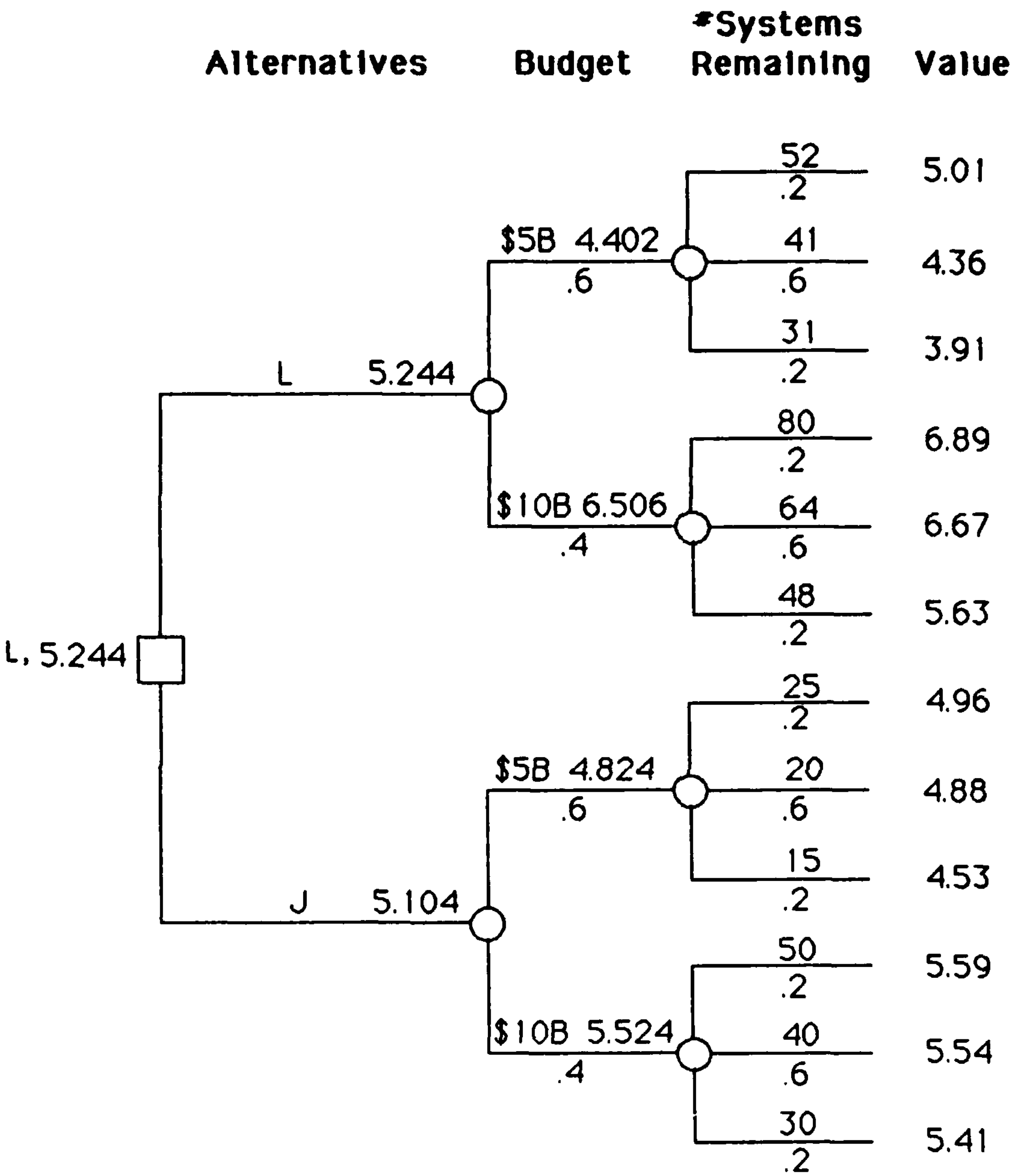



Figure 12. Decision Tree for Unknown Budget Levels and Unknown Levels of CM

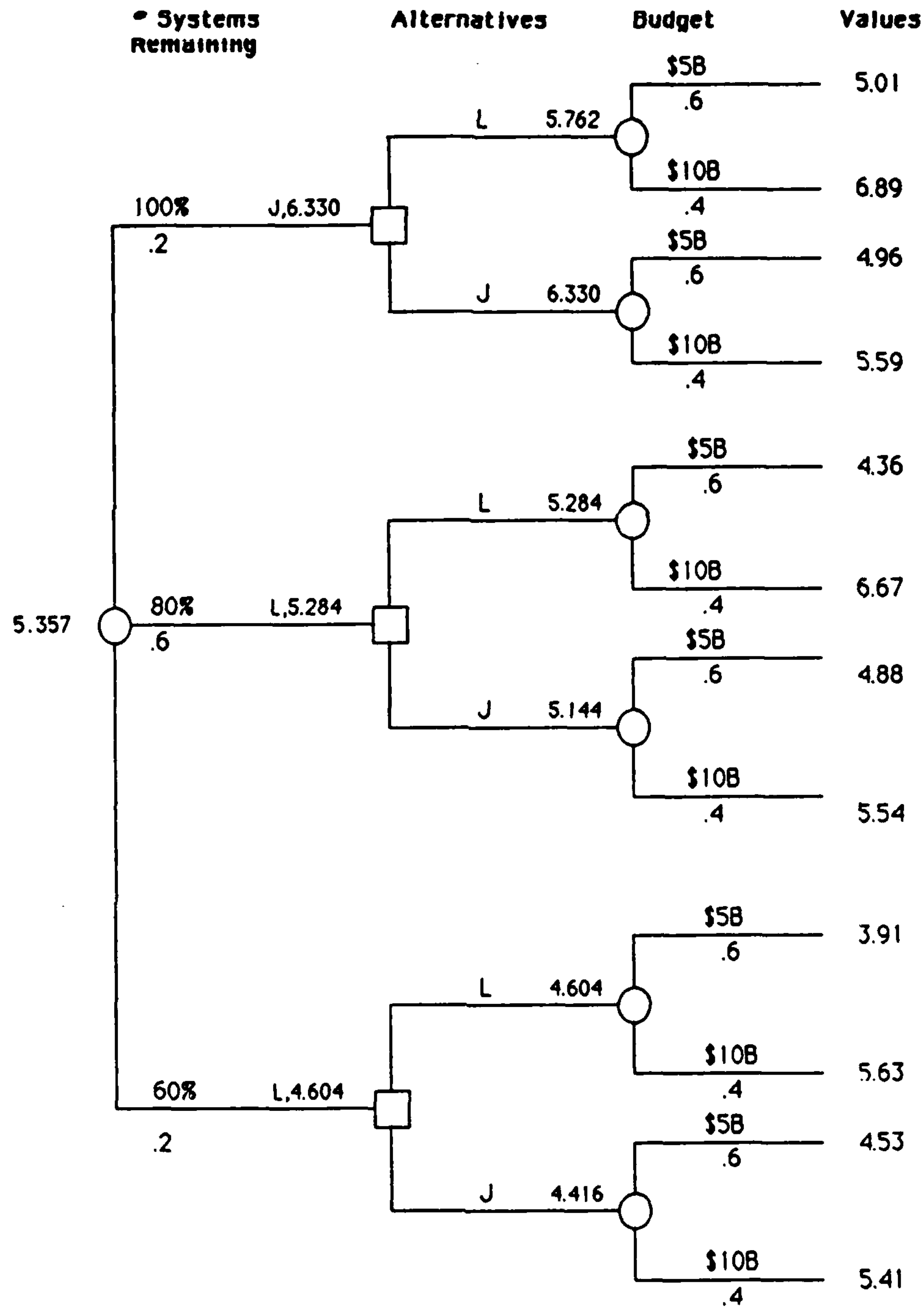



Figure 13. Decision Tree for Known CM and Unknown Budget Levels

methodology also included the development of a value function for the decision maker and a way in which to derive R, S and TA.

No specific conclusions can be drawn from this study as real data was not used. Overall conclusions and recommendations will be discussed in detail in Chapter 5.

## IV. Analytical Hierarchy Process

Another method in which to examine the LIGHTSAT decision is through the use of the analytical hierarchy process (AHP). Dr. Thomas L. Saaty developed AHP theory as a way of combining subjective judgments with personal values in solving or analyzing complex decisions. AHP is based upon three principles: the construction of hierarchies, establishing priorities and maintaining logical consistency (27:17-22). Using a hierarchial approach, the decision is structured as a tree with the overall goal at the top. The levels of criteria branch out from the goal with the intermediate levels of criteria below the primary criteria levels until finally the alternatives are at the bottom of the tree. By visually structuring the problem in a hierarchial manner, the relationships between the goal, criteria, alternatives and outcomes are clearly delineated. The tree also serves as a vehicle to convey the decision process to the decision makers in a concise manner. Expert Choice (EC) is a software package that allows decisions to be modeled through AHP.

The focus of this chapter is not to provide a definitive answer (as much of the information is classified) but rather to provide a methodology for the decision makers to use. A sample analysis will be done in order to

demonstrate the approach. The methodology should allow decision makers to gain considerable insight into critical parts of this decision process. The insight gained should lead to further studies being done in other areas of the problem.

Methodology

The problem, as defined earlier in this study, is to assist Army leaders in deciding whether a light satellite system should be procured and deployed to meet the needs of the battlefield commander in the RSTA arens. The method in which this will be analyzed will be to select the best battlefield intelligence system that can provide reconnaissance, surveillance and target acquisition to the theater commander across the spectrum of the entire battlefield. In looking at the alternatives, many were eliminated due to the scope of this study. The two alternatives that will be analyzed will be LIGHTSAT and JSTARS. This methodology can be used in analyzing any combination of systems.

The methodology combines the operational considerations of the systems with each of the system's technical capabilities (Figure 14). From a global perspective, the alternatives were evaluated by considering the types of warfare and the areas of the battlefield. Then the hierarchy focused in on the technical capabilities of each

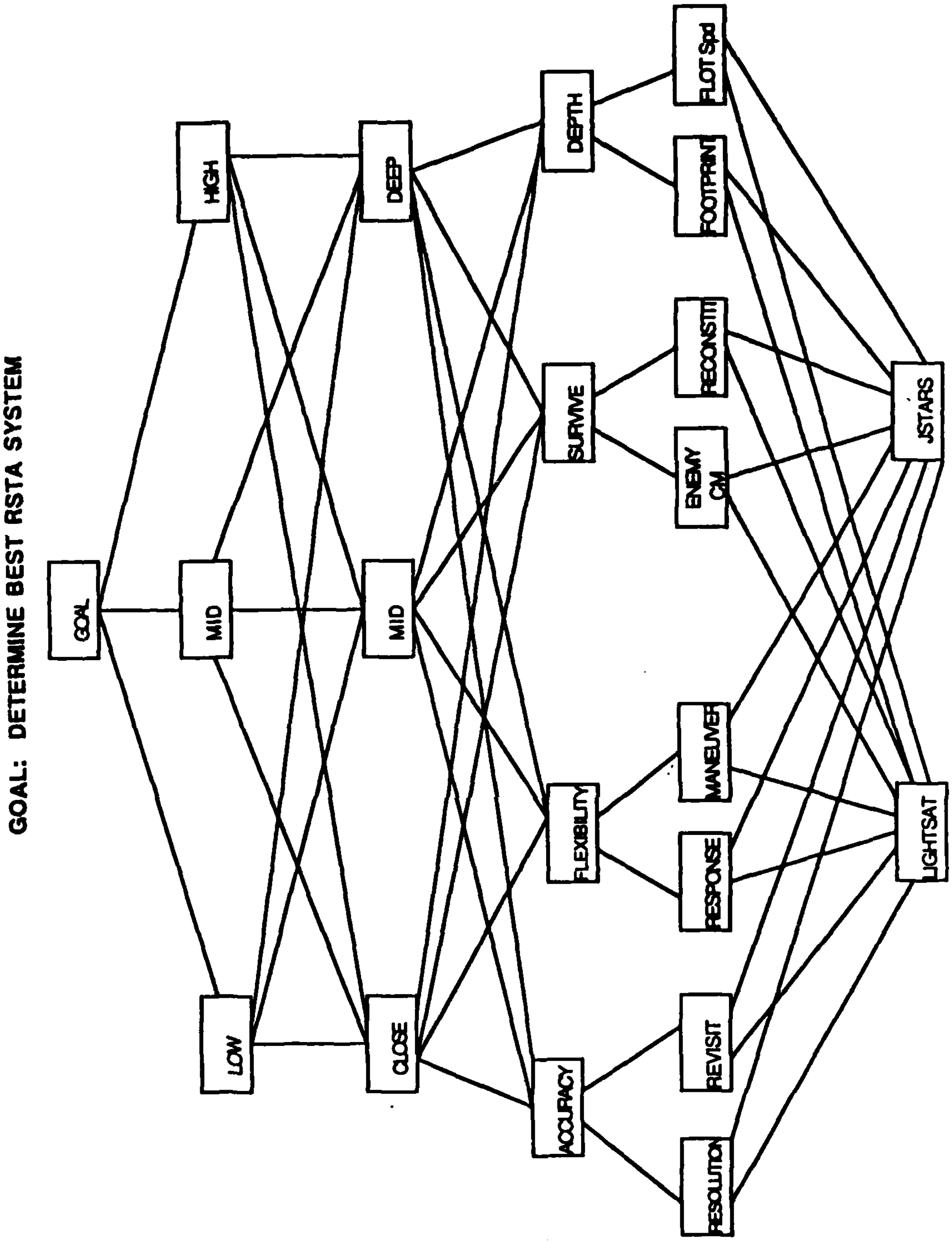



Figure 14. Hierarchial Structure

system. AHP should yield critical information about both LIGHTSAT and JSTARS to the decision makers.

Assumptions

For this study, a budget of $5 billion is assumed over a 10 year period. This assumption allows for a precise number of systems of each type. It is assumed that a Corps orbit of JSTARS aircraft will cost approximately $1 billion. A JSTARS aircraft will also be assumed to last over this entire 10 year period.

To launch a LIGHTSAT into orbit, a cost of $32 million will be assumed for the satellite and the booster. Continuous coverage over a theater such as Central Europe would require approximately 48 to 80 satellites between the altitudes of 400 to 1000 miles (10). The lifespan of a LIGHTSAT will be assumed to be 3.33 years. Ignoring ground support costs (which may be considerable), a total of 152 LIGHTSATs could be purchased and put to orbit over a 10 year period and a $5 billion budget. That would allow for 50 LIGHTSATs over each period of 3.3 years. Failure rates of both LIGHTSAT and JSTARS were not considered in this analysis.

A sample analysis will be performed using AHP. The structure of the hierarchy does not consider any one specific theater or type of conflict. Continuous coverage

will also be assumed for each alternative as the branches of the hierarchy are evaluated.

## Model Structure

The model, as seen in Figure 14, focused not on a specific theater, but on the potential benefits of increased RSTA througout the world and in varying types of conflict. With an overall goal of assisting the Army leadership in determining the effectiveness of a LIGHTSAT system and the optimum RSTA system (for this part of the study the elements R, S and TA are grouped together to simplify the process), the first level of criteria was the type of warfare that the systems might be called upon to perform in.

Types of Warfare. After reviewing current doctrine, the levels of warfare were broken down into low, mid and high intensity warfare. Low intensity warfare would resemble conflict in Central America or Grenada where rapid deployment is imperative and limited military force would be used to achieve specific objectives. It would also include activities prior to conflict, such as the gathering of information prior to hostilities being initiated. Hostilities may even be avoided if the intelligence level is sufficiently high enough.

Mid intensity warfare might include a scenario in Southwest Asia. In this case, U.S. forces would have to deployed to an area that does not already possess a

substantial U.S. military infrastructure. Facing an enemy that may possess modern Soviet hardware in an area that we are not thoroughly familiar with, will require a battlefield intelligence system that can become the "eyes" of the commander.

An example of high intensity warfare would be a scenario in Central Europe where NATO forces were engaging Warsaw Pact forces. This type of conflict would consist of intense combat using every existing weapon system.

Areas of the Battlefield. Each level of warfare was then divided into the three main areas of the battlefield - close, mid and deep. For this study, the close battle is defined as the area from the FLOT out to 20 kilometers. The mid battle ranges from 20 to 100 kilometers. The deep battle extends from 100 to 300 kilometers.

Technical Criteria. Each system was divided into four areas - accuracy, survivability, flexibility and depth. For this study, accuracy is defined as the system's ability to locate and identify targets in a precise manner. Survivability is the manner in which the system can perform its mission in the face of enemy countermeasures as well as how much effort is required to restore a comparable system. Flexibility is best defined as a combination of mission responsiveness and the number of varying scenarios that the system can operate in. Depth is the area of the battlefield

that can be covered by the system. These criteria were determined to be the most critical elements in evaluating the systems. These areas were subjectively arrived at based upon experience and research.

Technical Criteria - Intermediate Level. Each of the four areas of criteria were then further divided into intermediate levels. Accuracy was determined to be dependent upon the amount of resolution and the revisit time achieved by the system.

Survivability was dependent upon the countermeasures taken by the enemy and the ability to reconstitute any losses that were incurred.

Flexibility was found to be dependent upon the system response time to the theater commander's taskings and the maneuverability of each system to follow the fluid battlefield.

Lastly, depth was determined to be dependent upon the footprint size of each system and the FLOT speed.

Alternatives. Finally, the alternatives - LIGHTSAT and JSTARS - were placed beneath the intermediate levels of technical criteria.

## Model Weighting

Each level, beginning with the levels of warfare, were weighted based upon comparing the importance of each node to the other nodes. This method, the pairwise comparision

technique, was based upon any available quantifiable measurements that were known and subjective judgments that synthesized all available data and personal experiences. It is important to note that the following analysis, including weights and judgments are not based on actual data. The intent of this chapter is to provide a viable methodology. The decision maker can incorporate the best available data and develop specific insight into the decision using this methodology.

For example, when weighting the levels of warfare in this sample analysis, mid intensity warfare was considered more important than a low intensity conflict. High intensity warfare was considered strongly more important than low intensity warfare and more important than a mid intensity conflict. It should be noted that these weightings are not probabilities but rather levels of importance. High intensity warfare would hold the lowest probability and the highest degree of importance.

In a high intensity conflict, the deep battle was strongly more important than the mid and close battles and the mid battle was judged more important than the close battle. Each level of the hierarchy down to the alternatives were weighted using similar procedures to obtain the final weightings. A complete listing of all weightings are located in Appendix C.

The alternatives were then weighted by preference by determining which alternative was preferred in respect to a specific intermediate technical criteria - for example, resolution in the accuracy role for the deep battle in a high intensity conflict. LIGHTSAT and JSTARS were evaluated this way for each of the 72 branches of the hierarchy.

Sample Analysis

Each of the 72 branches of the tree were then synthesized to come up with a composite preference. This sample answer was based upon the subjective judgments that were made when weighting each level of the hierarchy and the preferences for each alternative. In the sample analysis, the overall preference was:

| | |
|---|---|
| LIGHTSAT | .601 |
| JSTARS | .399 |

Sensitivity Analysis

Sensitivity analysis of the entire structure lends considerable insight into the nodes of the tree and determines which values, if any, may alter the overall result when they are changed. The model is evaluated with all variables set to a median value. Then one variable is set at its low and high values. This yields low and high values for the model. This procedure is followed for all variables. The difference between the extreme values of the model for each variable is a measure of how sensitive the

decision is to that variable. A more dynamic approach can be taken by varying multiple variables simulaneously. This procedure may be the one that most closely resembles the battlefield.

Observations

Just as weightings and preferences can be synthesized for the overall goal, a synthesis can be performed at any node. If a synthesis was done at the levels of conflict the results would be as follows.

Table 7. Summary for Levels of Conflict

| | Low | Mid | High |
|---|---|---|---|
| LIGHTSAT | .585 | .606 | .602 |
| JSTARS | .415 | .394 | .398 |

The preferred system for each level of conflict (LIGHTSAT in each case) is shown based upon the judgments made. The overall preference must also be LIGHTSAT as the ultimate dedcision is a combination of weightings of the 3 levels of conflict.

Sensitivity analysis of the hierarchial structure permits several conclusions to be drawn. Figures 15, 16 and 17 are examples of sensitivity analysis for the overall goal. The remaining sensitivity analyses are found in Appendix D. There is very little sensitivity within the levels and nodes of the structure. Changing the weightings of the levels of conflict or the areas of the battlefield

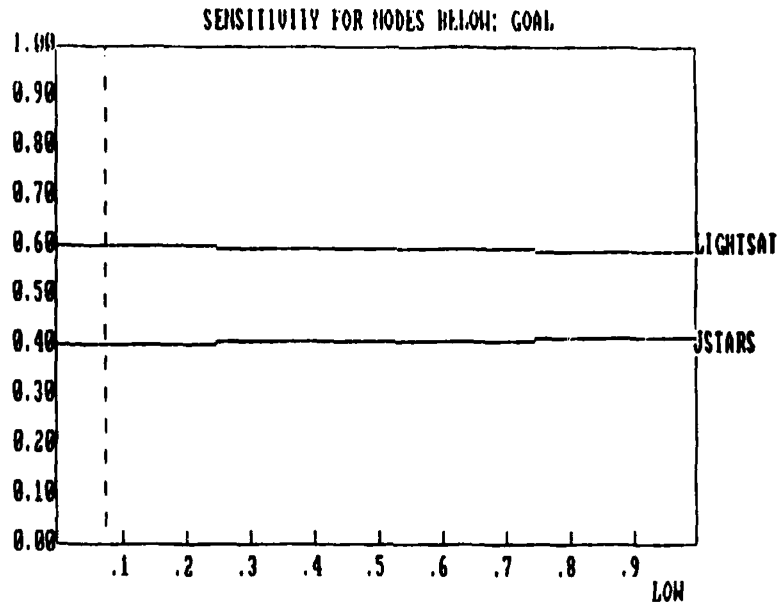



Figure 15. Sensitivity Analysis on the Goal for Low Intensity Conflict

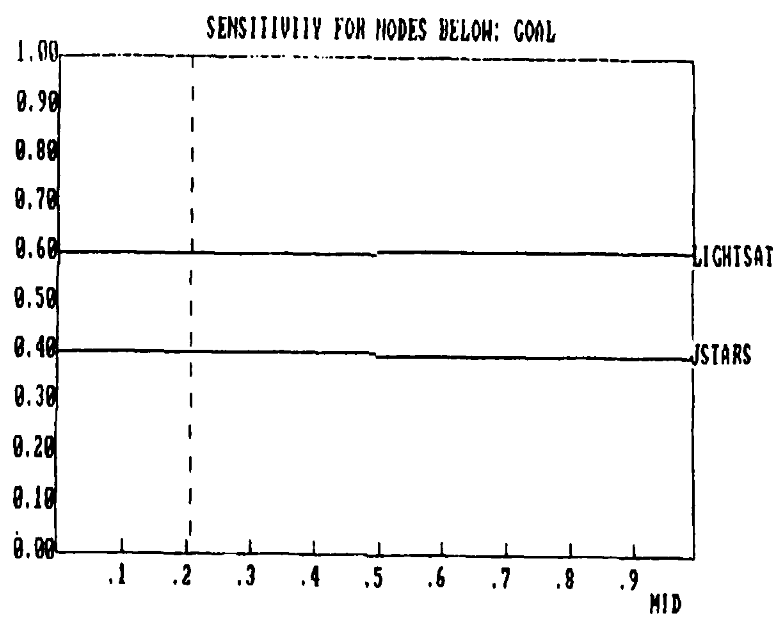



Figure 16. Sensitivity Analysis on the Goal for Mid Intensity Conflict

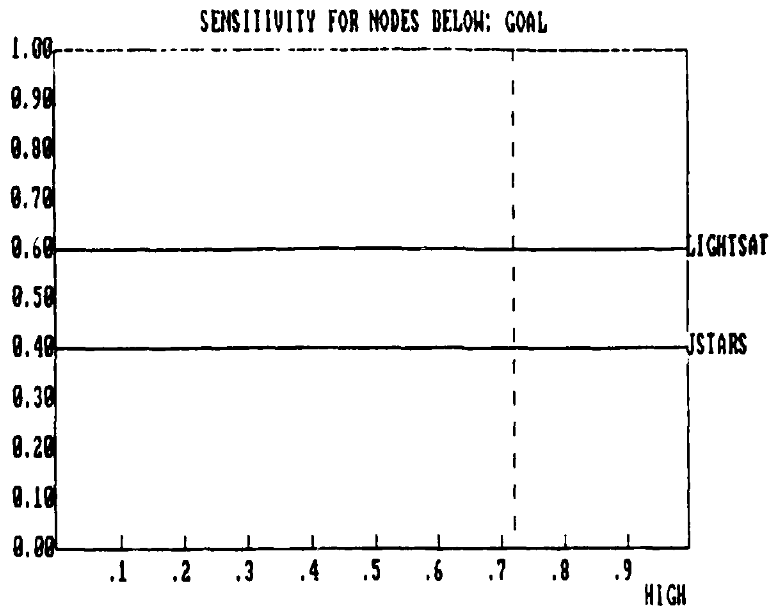



Figure 17. Sensitivity Analysis on the Goal for High Intensity Conflict

will not alter the final preference.

The reason for this insensitivity is due to the performance of the two systems in the deep battle. LIGHTSAT is capable of a 300 mile footprint anywhere on the battlefield. JSTARS will only be capable of approximately a 150 mile footprint beyond the FLOT. The rationale behind JSTARS' footprint limitation is that due to survivability factors, the aircraft must be positioned 100 to 150 kilometers in back of the FLOT. The domination of the LIGHTSAT alternative over the JSTARS alternative in the deep battle causes the insensitivity. Despite better performance

in many other areas, JSTARS cannot overcome the limitations of not being able to see beyond 150 miles of the FLOT.

Through an analysis of this type, considerable insight is gained into the decision process. As described earlier, the ability to see deep was an important factor in the overall preference. If the capability to see deep by both LIGHTSAT and JSTARS is judged to be equal, the preferences made in the hierarchial structure for the deep battle for each system would be judged equal and then the overall goal preference changes. The overall goal preference would be as follows:

Table 8. Comparision of LIGHTSAT and JSTARS Based upon Performance in the Deep Battle

| | LIGHTSAT > JSTARS IN DEEP BATTLE | LIGHTSAT = JSTARS IN DEEP BATTLE |
|---|---|---|
| LIGHTSAT | .601 | .467 |
| JSTARS | .399 | .533 |

As stated earlier, the hierarchial structure is a simple way to convey the nature of the decision to the decision makers. With relative ease, the structure can be altered to reflect new information based upon measurements and judgments. As an initial effort into the decision process, AHP can provide vital insight and direction into areas of the structure that require validation through further research and study.

# V. Conclusions and Recommendations

This study was an attempt to develop a methodology to assist Army leaders in making a strategic decision concerning light satellites. In general, battlefield commanders must have responsive RSTA systems to help counteract the Warsaw Pact superiority in personnel and equipment. As laid out in the Competitive Strategies concept, the United States and its allies must leverage off of key technological programs to seize the initiative.

To accomplish this leverage, many critical decisions will have to be made in the near future. These decisions will dictate the direction that will be taken in these times of fiscal restraint. Two methodologies were explored in this research, decision analysis and the analytical hierarchy process, that will provide insight and a systematic and intelligent approach to making these decisions.

## Decision Analysis Methodology

The decision analysis methodology is a comprehensive, logical and quantitative approach to decision making. The decision is decomposed into variables, alternatives, values and outcomes and then the courses of action are analyzed. The decision analysis cycle can be iterated several times as new information is gathered and applied. Uncertainty and

risk are introduced into the decision process and illustrates the best solution under uncertain conditions.

Besides providing a roadmap to the best solution, decision analysis can yield an expected value of information for each variable. This capability offers the decision maker considerable insight into how much money should be invested in order to reduce the uncertainty in the decision problem. The expected value of information calculation sets bounds on the extent of research that should be conducted to eliminate uncertainty.

This approach requires a great amount of interaction with the decision maker. It also requires the decision maker to fully state his or her value function. This may cause considerable problems due to the sensitive nature of the decision.

For a critical and strategic decision, such as the LIGHTSAT one, decision analysis offers considerable insight into the decision. Through the examination of all available information, preferences and values decision analysis illustrates how the decision should be made. This capability documents the state of information currently available to the decision maker. The decision maker's close interaction with the decision analyst allows the process to closely resemble reality. "It is rare that an organization performs a decision analysis on one of its major decisions

without obtaining new insight into its organizational structure" (13:26). Decision analysis is a detailed, rigorous and valid approach that would assist the Army in deciding whether LIGHTSAT is needed.

Analytical Hierarchy Process

The analytical hierarchy process is a valid aid to decision makers in the decision process. The overall goal of the decision problem is decomposed into levels of criteria and these various levels are weighted based upon the relative importance of each variable. This methodology allows the decision maker insight into the critical parts of the decision through sensitivity analysis.

As this methodology is based upon subjective judgments as well as quantifiable measurements, each of the subjective judgments must be verified to the greatest extent possible.

The manner of presentation, through the tree structure, assists the decision maker in understanding the decision process fully.

One drawback to this methodology is that the treatment of uncertainty and risk is not as th rough as in decision analysis.

The analytical hierarchy process is a valid way of gaining insight into the decision. When there exists a great deal of uncertainty in the decision process, AHP becomes less rigorous in the overall analysis. As an

initial attempt at analyzing the decision, AHP is an excellent decision aid. On unique and strategic decisions, the melding of AHP and decision analysis into a complete analysis package would provide a quality analysis for the decision maker.

Recommendations for Further Study

Within the context of the decision process, further study is required into how decision makers should make trade-off value judgments for major weapon systems. The value function developed in this effort requires refinement and validation. Extensive interviews with high level battlefield commanders would prove worthwhile in assessing the validity of the value function.

The models for R, S and TA need to be developed further. Additional refinement should be based upon existing models and operational experience.

The scope of the study should be enlarged to include other alternatives as this effort was limited to two alternatives. Further research into the levels of the budget and enemy countermeasures that could be expected would also be of assistance in the decision process.

The potential benefits of LIGHTSAT require further research into the many areas that have been discussed. A follow on study, using classified data with either or both of the methodologies presented, is essential and would prove

beneficial to the decision maker. These methodologies should prove extremely useful in many similar decisions.

Each methodology should be applied to the different theaters of concern, levels of warfare and areas of the battlefield. Detailed analysis of LIGHTSAT throughout the spectrum of combat may lead to startling conclusions. The need to observe the benefits of a LIGHTSAT system in a crisis type situation such as Grenada or the Falklands is as necessary as the need to observe system performance in Central Europe or Southwest Asia.

The flexibility that would be gained from a LIGHTSAT system in terms of reconstitution should also be studied further. The contribution of LIGHTSAT to reconstituting current national satellite systems may be substantial.

The application of LIGHTSAT to other military missions, such as communications and fire support also requires additional study.

Specific satellite architectures must be developed and based upon the theater and type of coverage required and specific satellite technical characteristics.

The potential benefits that may be derived from a LIGHTSAT system require that the efforts of the operational and analytic communities be combined to fully explore the realm of possibilities.

## Closing Remarks

The reliance of the U.S. armed forces on large, very expensive and multi role satellites appears to limit the military options normally desired by military commanders. A look at the structure of the armed forces illustrates a mix of heavy and light forces capable of operating around the world. Why should the structure of space assets be any different?

The development of the current U.S. capability in space has evolved into a structure that seems responsive to high level, national assets rather than theater commanders. A cost effective satellite system that is responsive to theater commanders would allow for increased flexibility and capability across the battlefield.

The potential benefits of a revolutionary type satellite system, similar to LIGHTSAT, require that research and development be continued until the concept is proven or discarded. The ultimate answer must depend upon the system's actual capabilities and cost effectiveness and not bureaucratic differences in thinking.

The enhancement of the military's capabilities through the utilization of space is strikingly similar to the controversial development of air power over 50 years ago. The advantages of the military use of space in the preservation of peace are still largely unrealized. The

role of space must be fully understood or else the U.S. may lose the ultimate high ground that is so vital to national security.

# Appendix A: Computer Software

Several commercially produced software packages were used in performing the sample analyses. These software packages would prove useful in performing the methodologies described in Chapters 3 and 4.

## Chapter 3

SAS. A statistical analysis package that enabled the value function to be derived from personal interviews through plotting the individual points and producing a best fit curve. SAS requires a firm background in statistics in order to analyze the output.

InDia. This was an influence diagram solver that could be used to model and solve a decision process. Prior knowledge of decision analysis techniques and influence diagrams is necessary before using InDIA.

## Chapter 4

Expert Choice. This was a decision support package that allows any decision to be modeled in a hierarchial structure. Each level of the structure can be weighted based upon judgments of the decision maker and an overall preference can then be obtained. Expert Choice is relatively easy to use and possesses a significant capability in modeling decisions.

## Appendix B: Summary of RSTA Levels

### Summary of RSTA Levels for JSTARS (Budget = $10 billion)

| | W % tgts w/in 150 miles | X % tgts not currently located | Y % tgts located full cap | Z@ % cap after CM | curent level | new level |
|---|---|---|---|---|---|---|
| R | .667 | .6 | .85 | .99 | .4 | .737 |
| | .667 | .6 | .85 | .98 | .4 | .733 |
| | .667 | .6 | .85 | .95 | .4 | .723 |
| S | .667 | .667 | .75 | .99 | .333 | .660 |
| | .667 | .667 | .75 | .98 | .333 | .657 |
| | .667 | .667 | .75 | .95 | .333 | .647 |
| TA | .667 | .8 | .7 | .99 | .2 | .570 |
| | .667 | .8 | .7 | .98 | .2 | .566 |
| | .667 | .8 | .7 | .95 | .2 | .555 |

@ -> (22:40)

### Summary of RSTA Levels for LIGHTSAT (Budget = $10 billion)

| | W % tgts w/in 300 miles | X % tgts not currently located | Y % tgts located full cap | Z % cap after CM | curent level | new level |
|---|---|---|---|---|---|---|
| R | .95 | .6 | .75 | 1.0 | .4 | .827 |
| | .95 | .6 | .75 | .95 | .4 | .806 |
| | .95 | .6 | .75 | .75 | .4 | .721 |
| S | .95 | .667 | .7 | 1.0 | .333 | .774 |
| | .95 | .667 | .7 | .95 | .333 | .751 |
| | .95 | .667 | .7 | .75 | .333 | .663 |
| TA | .95 | .8 | .667 | 1.0 | .2 | .707 |
| | .95 | .8 | .667 | .95 | .2 | .682 |
| | .95 | .8 | .667 | .75 | .2 | .580 |

# Appendix C: Listing of Hierarchy Structural Weightings

DETERMINE BEST RECON SYSTEM
TALLY FOR SYNTHESIS OF LEAF NODES WITH RESPECT TO GOAL

| LEVEL 1 | LEVEL 2 | LEVEL 3 | LEVEL 4 | LEVEL 5 |
|---|---|---|---|---|
| HIGH =0.722 | | | | |
| | DEEP =0.506 | | | |
| | | ACCURACY =0.218 | | |
| | | | RESOLUTN =0.131 | |
| | | | | LIGHTSAT =0.098 |
| | | | | JSTARS =0.033 |
| | | | REVISIT =0.087 | |
| | | | | LIGHTSAT =0.065 |
| | | | | JSTARS =0.022 |
| | | SURVIVE =0.164 | | |
| | | | ENEMY CM =0.098 | |
| | | | | LIGHTSAT =0.059 |
| | | | | JSTARS =0.039 |
| | | | RECONSTI =0.065 | |
| | | | | LIGHTSAT =0.039 |
| | | | | JSTARS =0.026 |
| | | DEPTH =0.081 | | |
| | | | FOOTPRNT =0.048 | |
| | | | | LIGHTSAT =0.036 |
| | | | | JSTARS =0.012 |
| | | | FLOT SPD =0.032 | |
| | | | | JSTARS =0.019 |
| | | | | LIGHTSAT =0.013 |
| | | FLEXIBIL =0.044 | | |
| | | | RESPONSE =0.026 | |
| | | | | LIGHTSAT =0.020 |
| | | | | JSTARS =0.007 |
| | | | MANEUVER =0.018 | |
| | | | | JSTARS =0.011 |
| | | | | LIGHTSAT =0.007 |
| | MID =0.146 | | | |
| | | ACCURACY =0.064 | | |
| | | | RESOLUTN =0.038 | |
| | | | | JSTARS =0.023 |
| | | | | LIGHTSAT =0.015 |
| | | | REVISIT =0.025 | |
| | | | | JSTARS =0.017 |
| | | | | LIGHTSAT =0.008 |
| | | SURVIVE =0.048 | | |
| | | | ENEMY CM =0.029 | |
| | | | | LIGHTSAT =0.017 |
| | | | | JSTARS =0.011 |
| | | | RECONSTI =0.019 | |
| | | | | LIGHTSAT =0.011 |
| | | | | JSTARS =0.008 |
| | | DEPTH =0.021 | | |
| | | | FOOTPRNT =0.012 | |
| | | | | JSTARS =0.007 |
| | | | | LIGHTSAT =0.005 |
| | | | FLOT SPD =0.008 | |
| | | | | JSTARS =0.006 |
| | | | | LIGHTSAT =0.003 |

```
LEVEL 1     LEVEL 2     LEVEL 3          LEVEL 4          LEVEL 5
-------     -------     -------          -------          -------

.           .           FLEXIBIL =0.014
.           .           .                RESPONSE =0.008
.           .           .                .                JSTARS   =0.005
.           .           .                .                LIGHTSAT =0.003
.           .           .                MANEUVER =0.006
.           .           .                .                JSTARS   =0.004
.           .           .                .                LIGHTSAT =0.002
.           CLOSE    =0.070
.           .           ACCURACY =0.034
.           .           .                RESOLUTN =0.025
.           .           .                .                JSTARS   =0.015
.           .           .                .                LIGHTSAT =0.010
.           .           .                REVISIT  =0.008
.           .           .                .                JSTARS   =0.006
.           .           .                .                LIGHTSAT =0.003
.           .           SURVIVE  =0.022
.           .           .                ENEMY CM =0.013
.           .           .                .                LIGHTSAT =0.008
.           .           .                .                JSTARS   =0.005
.           .           .                RECONSTI =0.009
.           .           .                .                LIGHTSAT =0.005
.           .           .                .                JSTARS   =0.004
.           .           FLEXIBIL =0.010
.           .           .                RESPONSE =0.007
.           .           .                .                JSTARS   =0.004
.           .           .                .                LIGHTSAT =0.003
.           .           .                MANEUVER =0.002
.           .           .                .                JSTARS   =0.002
.           .           .                .                LIGHTSAT.80E-03
.           .           DEPTH    =0.005
.           .           .                FOOTPRNT =0.003
.           .           .                .                JSTARS   =0.002
.           .           .                .                LIGHTSAT =0.001
.           .           .                FLOT SPD =0.002
.           .           .                .                JSTARS   =0.001
.           .           .                .                LIGHTSAT.51E-03
MID      =0.205
.           DEEP     =0.138
.           .           ACCURACY =0.068
.           .           .                RESOLUTN =0.041
.           .           .                .                LIGHTSAT =0.031
.           .           .                .                JSTARS   =0.010
.           .           .                REVISIT  =0.027
.           .           .                .                LIGHTSAT =0.020
.           .           .                .                JSTARS   =0.007
.           .           DEPTH    =0.037
.           .           .                FOOTPRNT =0.022
.           .           .                .                LIGHTSAT =0.017
.           .           .                .                JSTARS   =0.006
.           .           .                FLOT SPD =0.015
.           .           .                .                LIGHTSAT =0.009
.           .           .                .                JSTARS   =0.006
```

| LEVEL 1 | LEVEL 2 | LEVEL 3 | LEVEL 4 | LEVEL 5 |
|---|---|---|---|---|
| | | FLEXIBIL =0.021 | | |
| | | | RESPONSE =0.013 | |
| | | | | LIGHTSAT =0.010 |
| | | | | JSTARS =0.003 |
| | | | MANEUVER =0.009 | |
| | | | | JSTARS =0.005 |
| | | | | LIGHTSAT =0.003 |
| | | SURVIVE =0.011 | | |
| | | | ENEMY CM =0.008 | |
| | | | | LIGHTSAT =0.006 |
| | | | | JSTARS =0.003 |
| | | | RECONSTI =0.003 | |
| | | | | LIGHTSAT =0.002 |
| | | | | JSTARS =0.001 |
| | MID =0.046 | | | |
| | | ACCURACY =0.023 | | |
| | | | RESOLUTN =0.016 | |
| | | | | JSTARS =0.009 |
| | | | | LIGHTSAT =0.006 |
| | | | REVISIT =0.008 | |
| | | | | JSTARS =0.005 |
| | | | | LIGHTSAT =0.003 |
| | | FLEXIBIL =0.009 | | |
| | | | RESPONSE =0.006 | |
| | | | | JSTARS =0.003 |
| | | | | LIGHTSAT =0.002 |
| | | | MANEUVER =0.004 | |
| | | | | JSTARS =0.003 |
| | | | | LIGHTSAT =0.001 |
| | | DEPTH =0.009 | | |
| | | | FOOTPRNT =0.006 | |
| | | | | JSTARS =0.003 |
| | | | | LIGHTSAT =0.002 |
| | | | FLOT SPD =0.004 | |
| | | | | JSTARS =0.003 |
| | | | | LIGHTSAT =0.001 |
| | | SURVIVE =0.004 | | |
| | | | ENEMY CM =0.003 | |
| | | | | LIGHTSAT =0.002 |
| | | | | JSTARS .98E-03 |
| | | | RECONSTI.98E-03 | |
| | | | | LIGHTSAT.59E-03 |
| | | | | JSTARS .39E-03 |
| | CLOSE =0.021 | | | |
| | | ACCURACY =0.011 | | |
| | | | RESOLUTN =0.008 | |
| | | | | JSTARS =0.005 |
| | | | | LIGHTSAT =0.003 |
| | | | REVISIT =0.003 | |
| | | | | JSTARS =0.002 |
| | | | | LIGHTSAT.88E-03 |
| | | FLEXIBIL =0.004 | | |

| LEVEL 1 | LEVEL 2 | LEVEL 3 | LEVEL 4 | LEVEL 5 |
|---|---|---|---|---|
| | | | RESPONS =0.003 | |
| | | | | JSTARS =0.002 |
| | | | | LIGHTSAT =0.001 |
| | | | MANEUVER =0.001 | |
| | | | | JSTARS .86E-03 |
| | | | | LIGHTSAT.57E-03 |
| | | DEPTH =0.004 | | |
| | | | FOOTPRNT =0.003 | |
| | | | | JSTARS =0.002 |
| | | | | LIGHTSAT =0.001 |
| | | | FLOT SPD =0.001 | |
| | | | | JSTARS .85E-03 |
| | | | | LIGHTSAT.42E-03 |
| | | SURVIVE =0.002 | | |
| | | | ENEMY CM =0.001 | |
| | | | | LIGHTSAT.98E-03 |
| | | | | JSTARS .49E-03 |
| | | | RECONSTI.49E-03 | |
| | | | | LIGHTSAT.29E-03 |
| | | | | JSTARS .20E-03 |
| LOW =0.073 | | | | |
| | DEEP =0.046 | | | |
| | | ACCURACY =0.023 | | |
| | | | RESOLUTN =0.014 | |
| | | | | LIGHTSAT =0.010 |
| | | | | JSTARS =0.003 |
| | | | REVISIT =0.009 | |
| | | | | LIGHTSAT =0.007 |
| | | | | JSTARS =0.002 |
| | | FLEXIBIL =0.012 | | |
| | | | RESPONSE =0.008 | |
| | | | | LIGHTSAT =0.006 |
| | | | | JSTARS =0.002 |
| | | | MANEUVER =0.004 | |
| | | | | JSTARS =0.002 |
| | | | | LIGHTSAT =0.002 |
| | | DEPTH =0.008 | | |
| | | | FOOTPRNT =0.005 | |
| | | | | LIGHTSAT =0.004 |
| | | | | JSTARS =0.001 |
| | | | FLOT SPD =0.003 | |
| | | | | JSTARS =0.002 |
| | | | | LIGHTSAT =0.001 |
| | | SURVIVE =0.003 | | |
| | | | ENEMY CM =0.002 | |
| | | | | LIGHTSAT =0.002 |
| | | | | JSTARS .82E-03 |
| | | | RECONSTI.82E-03 | |
| | | | | LIGHTSAT.49E-03 |
| | | | | JSTARS .33E-03 |
| | MID =0.020 | | | |
| | | ACCURACY =0.010 | | |

```
LEVEL 1          LEVEL 2          LEVEL 3            LEVEL 4            LEVEL 5
-------          -------          -------            -------            -------

.                .                .                  RESOLUTN =0.007
.                .                .                  .                  JSTARS   =0.004
.                .                .                  .                  LIGHTSAT =0.003
.                .                .                  REVISIT  =0.003
.                .                .                  .                  JSTARS   =0.002
.                .                .                  .                  LIGHTSAT =0.001
.                .                FLEXIBIL =0.006
.                .                .                  RESPONSE =0.004
.                .                .                  .                  JSTARS   =0.002
.                .                .                  .                  LIGHTSAT =0.002
.                .                .                  MANEUVER =0.002
.                .                .                  .                  JSTARS   =0.001
.                .                .                  .                  LIGHTSAT.64E-03
.                .                DEPTH    =0.003
.                .                .                  FOOTPRNT =0.002
.                .                .                  .                  JSTARS   =0.001
.                .                .                  .                  LIGHTSAT.81E-03
.                .                .                  FLOT SPD =0.001
.                .                .                  .                  JSTARS  .68E-03
.                .                .                  .                  LIGHTSAT.34E-03
.                .                SURVIVE  =0.002
.                .                .                  ENEMY CM =0.001
.                .                .                  .                  LIGHTSAT.77E-03
.                .                .                  .                  JSTARS  .38E-03
.                .                .                  RECONSTI.38E-03
.                .                .                  .                  LIGHTSAT.23E-03
.                .                .                  .                  JSTARS  .15E-03
.                CLOSE    =0.007
.                .                ACCURACY =0.004
.                .                .                  RESOLUTN =0.003
.                .                .                  .                  JSTARS   =0.002
.                .                .                  .                  LIGHTSAT =0.001
.                .                .                  REVISIT .88E-03
.                .                .                  .                  JSTARS  .58E-03
.                .                .                  .                  LIGHTSAT.29E-03
.                .                FLEXIBIL =0.001
.                .                .                  RESPONSE.96E-03
.                .                .                  .                  JSTARS  .58E-03
.                .                .                  .                  LIGHTSAT.39E-03
.                .                .                  MANEUVER.48E-03
.                .                .                  .                  JSTARS  .29E-03
.                .                .                  .                  LIGHTSAT.19E-03
.                .                SURVIVE  =0.001
.                .                .                  ENEMY CM.69E-03
.                .                .                  .                  LIGHTSAT.46E-03
.                .                .                  .                  JSTARS  .23E-03
.                .                .                  RECONSTI.34E-03
.                .                .                  .                  LIGHTSAT.21E-03
.                .                .                  .                  JSTARS  .14E-03
.                .                DEPTH   .83E-03
.                .                .                  FOOTPRNT.62E-03
.                .                .                  .                  JSTARS  .41E-03
.                .                .                  .                  LIGHTSAT.21E-03
.                .                .                  FLOT SPD.21E-03
.                .                .                  .                  JSTARS  .12E-03
.                .                .                  .                  LIGHTSAT.83E-04
```

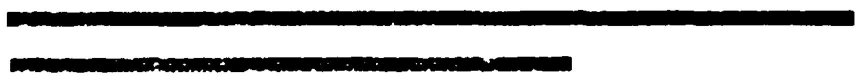
DETERMINE BEST RECON SYSTEM

SYNTHESIS OF LEAF NODES WITH RESPECT TO GOAL

OVERALL INCONSISTENCY INDEX = 0.05

LIGHTSAT 0.601

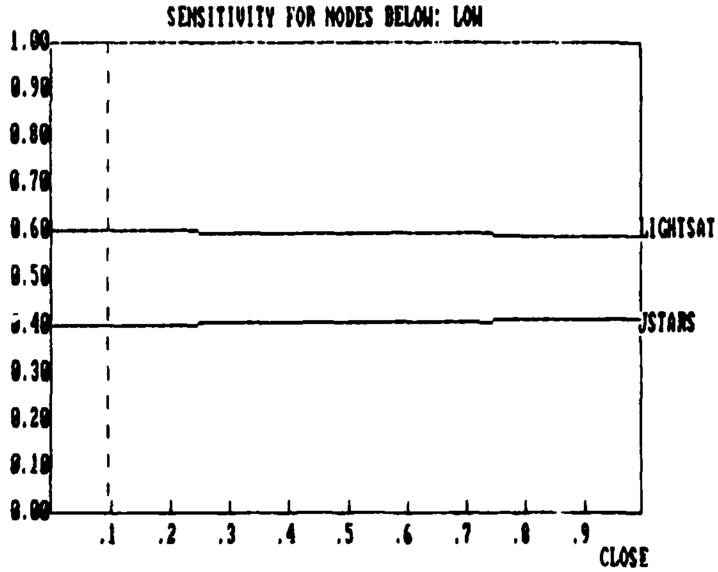
JSTARS 0.399



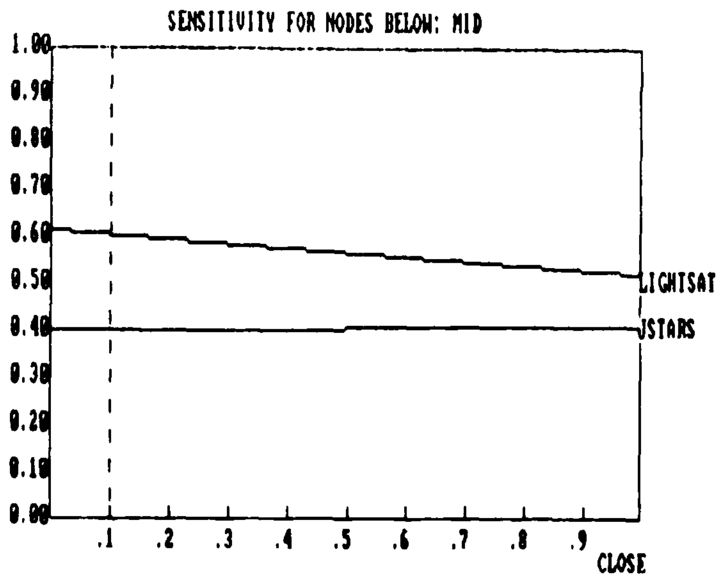
=====

1.000

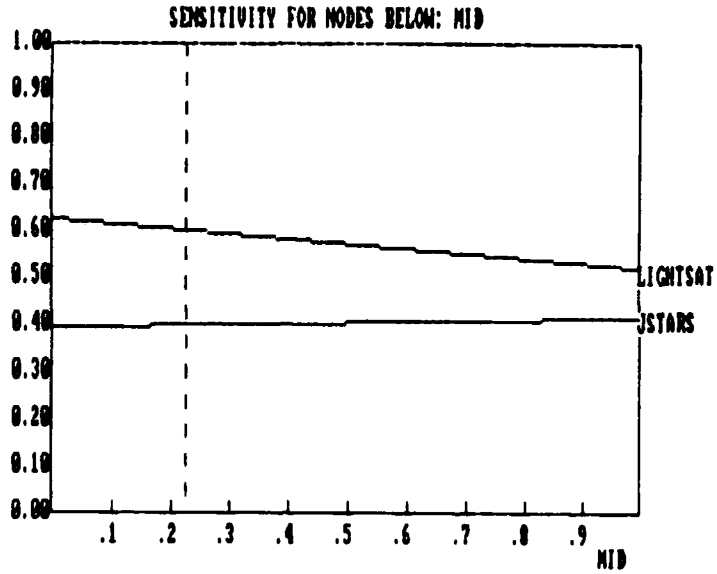
## Appendix D: Sensitivity Analysis for AHP



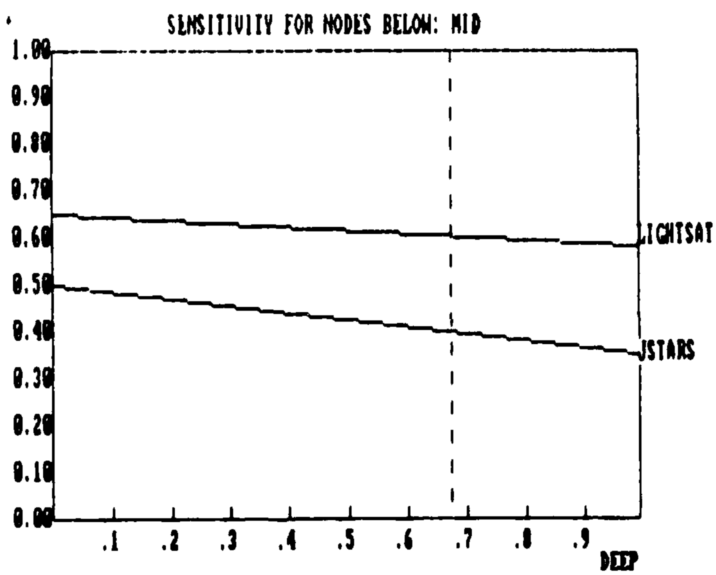

Sensitivity Analysis for Close, Mid and Deep Battle in Low Intensity Warfare



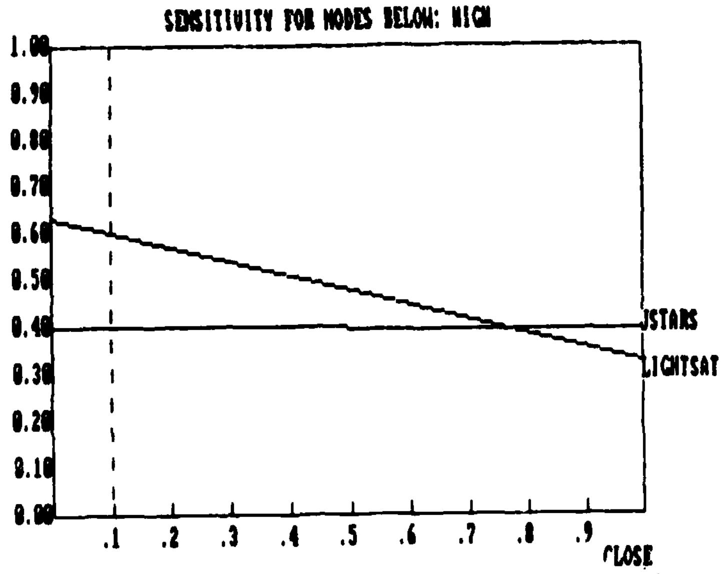

Sensitivity Analysis for Close Battle in Mid Intensity Warfare



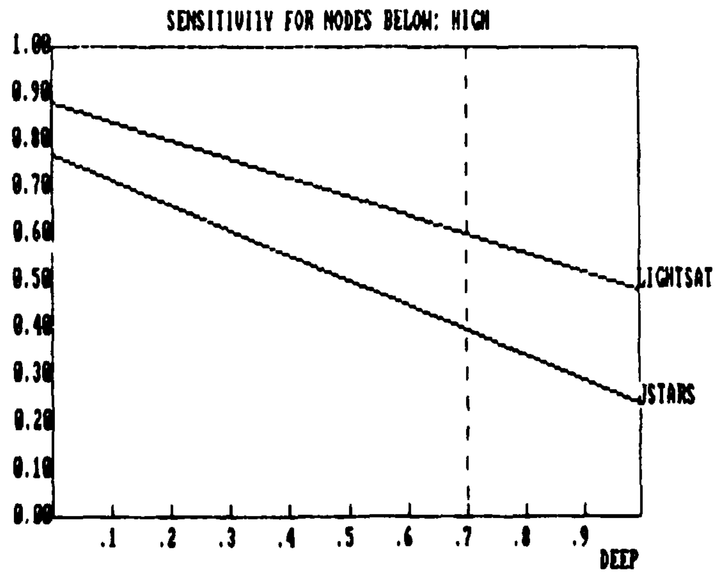

Sensitivity Analysis for Mid Battle
in Mid Intensity Warfare



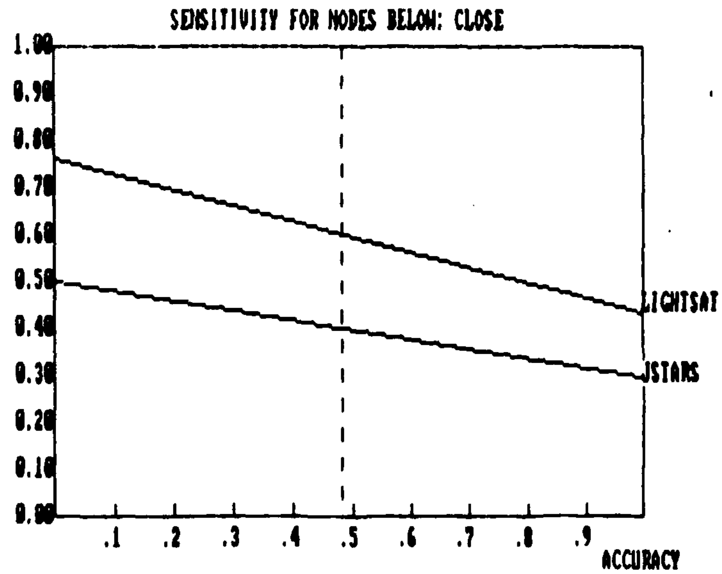

Sensitivity Analysis for Deep Battle
in Mid Intensity Warfare



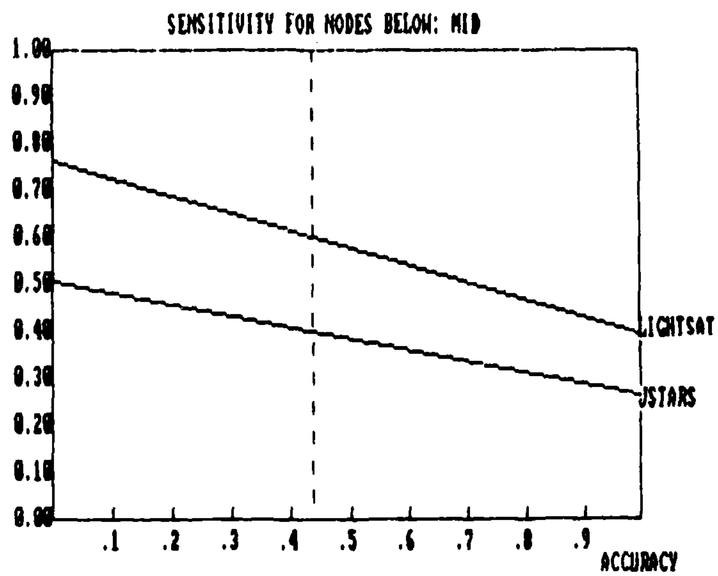

Sensitivity Analysis for Close and Mid Battle
in High Intensity Warfare



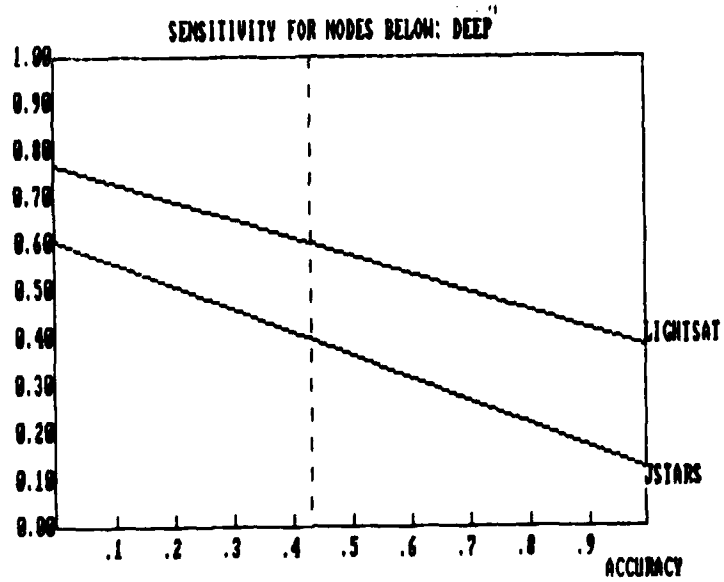

Sensitivity Analysis for Deep Battle
in High Intensity Warfare




Sensitivity Analysis for Accuracy, Flexibility, Survivability *and Depth* in Close Battle in High Intensity Warfare




Sensitivity Analysis for Accuracy, Flexibility, Survivability and Depth in Mid Battle in High Intensity Warfare




**Sensitivity Analysis for Accuracy, Flexibility, Survivability and Depth in Deep Battle in High Intensity Warfare**

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## Vita

Captain James R. Pierson was born on [redacted] He graduated from high school in 1975, in [redacted] He graduated from the United States Military Academy in 1979 with a Bachelor of Science degree and a commission in the United States Army. Upon graduation, he attended the Field Artillery Officer Basic Course at Fort Sill, Oklahoma. In February of 1980, he was assigned to the 1st Battalion (ABN), 319th Field Artillery, 82nd Airborne Division at Fort Bragg, North Carolina. He served as a Fire Support Team Chief, a Firing Battery Executive Officer and a Battalion Fire Support Officer. In November of 1983, he graduated from the Field Artillery Officer Advanced Course. Later that month, he was assigned to the 2nd Battalion, 41st Field Artillery, 3rd Infantry Division in the Federal Republic of Germany. He commanded a headquarters and headquarters battery for 24 months and a 155mm self-propelled firing battery for 12 months. Upon leaving Germany in June 1987, he reported to the School of Engineering, Air Force Institute of Technology, to pursue a Masters of Science degree in Space Operations.

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The purpose of this study was to assist senior Army leadership in determining whether light satellites (LIGHTSAT) should be procured to meet current and future reconnaissance, surveillance and target acquisition (RSTA) needs on the battlefield. Two methodologies were developed during this study - the decision analysis approach and the analytical hierarchy process. For each methodology, LIGHTSAT was evaluated against the Joint Surveillance Target Attack Radar System (JSTARS) alternative. Due to this being an unclassified study and that the effort was centered on developing methodologies, sample data was used in place of actual values (unless otherwise noted). The decision analysis methodology required an influence diagram of the overall decision, a value model that elicited outcomes for each alternative, a model that would help determine the level of reconnaissance, surveillance and target acquisition achieved by each alternative and an assessment of probabilities of certain events occurring. Detailed discussion was given to the development of the value model and to how reconnaissance, surveillance and target acquisition are measured. The use of decision analysis lends considerable insight into the decision through the expected value of perfect information (EVPI). EVPI illustrates how much additional money should be invested into reducing the uncertainty within the decision.

The analytical hierarchy process analyzed the decision through a hierarchy of objectives approach. Subjective judgments based upon experience were combined with quantifiable measurements to apply weightings to the various criteria within a level of the hierarchy. Preferences between the alternatives were then made. The synthesis of these preferences between alternatives and weightings yielded an overall preference for the decision. Sensitivity analysis of the hierarchial structure offered insight into the criteria that might alter the decision.

Among the recommendations provided was the need to validate these methodologies with actual classified data. Continued emphasis on enhancing the capabilities of the military commander through the use of space assets was considered essential.



END